CHAPTER 3: FACTORS AFFECTING WINTER-RUN CHINOOK

The decline of the winter-run chinook population resulted from the cumulative effects of degradation of spawning, rearing and migration habitats in the Sacramento River and Sacramento-San Joaquin Delta. Specifically, the population's decline was most likely precipitated by a combination of : 1) excessively warm water temperatures from releases at Shasta Dam, 2) hindering and blocking free passage of juveniles and adults at the Red Bluff Diversion Dam, 3) export of vast quantities of water from diversions in the south Delta, 4) heavy metal contamination from Iron Mountain Mine, and 5) entrainment to a large number of unscreened and poorly screened diversions. Climatic events exacerbated these habitat problems through extended droughts leading to low flows and higher temperatures, and through periodic El Niño conditions in the Pacific Ocean, which reduced salmon survival by altering ocean current patterns and productivity.

A host of other factors have also contributed to the decline of winter-run chinook but perhaps to a lesser degree. These include the various smaller water manipulation facilities and dams; extensive loss of rearing habitat in the lower Sacramento River and Sacramento-San Joaquin Delta through levee construction and marshland reclamation; and the interaction and predation by introduced species. Ocean and inland recreational and commercial salmon fisheries have likely impaired stock rebuilding efforts.

Many of these development projects occurred without sufficient consideration to the conservation of winter-run chinook (and other salmon populations) and their habitat. Other developments proceeded with the assumption that improved technology and management would compensate for the loss of habitat. Efforts under existing fisheries regulatory measures have failed to protect winter-run chinook as a healthy population, and as a result, the population was afforded protection under the Endangered Species Act (ESA) as a last resort to avert their extinction. Since its listing, many habitat problems have been improved to help preserve the winter-run chinook population. These include improved water temperatures and flow management for spawning, incubation, and rearing; improved passage of juveniles and adults at diversions dams on the upper Sacramento River; and tempering of water export in the Delta during late winter and early spring. However, increased protective measures and extensive habitat restoration will be necessary to fully recover Sacramento River winter-run chinook salmon.

I. FACTORS AFFECTING SPAWNING AND REARING HABITAT

Adverse Temperature Conditions: Upper Sacramento River
(Keswick Dam to Red Bluff Diversion Dam)

The upper Sacramento River above the Red Bluff Diversion Dam (RBDD) is the primary spawning ground of winter-run chinook. The winter-run chinook population is entirely dependent upon the provision of suitably cool water temperatures during their spawning, incubation and rearing period. Water temperatures in the upper Sacramento River result from the complex interaction of: (1) ambient air temperature, (2) volume of water, (3) water temperature at release from Shasta and Trinity dams, (4) total reservoir storage, (5) location of reservoir thermocline, (6) ratio of Spring Creek Powerplant release to Shasta Dam release, and (7) tributary inflows. Water temperature varies with location and distance downstream of Keswick Dam, and depends upon the annual hydrologic conditions and annual operation of the Shasta-Trinity Division of the Central Valley Project (CVP). In general, water released from Keswick Dam warms as it moves downstream during the summer and early fall months which are critical months for the successful development and survival of juvenile winter-run chinook.

Effects on Winter-run Chinook

Newly spawned and incubating winter-run chinook eggs and fry are the most sensitive life stages to elevated temperatures. Maximum survival of incubating eggs and pre-emergent fry occurs at water temperatures between 40°F and 56°F. Mortality of eggs increases substantially at 57.5°F and reaches 100% at 62°F (Seymour 1956, Combs and Burrows 1957, and Hinze 1959: as cited in Boles 1988). Pre-emergent fry appear more sensitive to warm water temperatures, and may have better survival when eggs are incubated at 55°F (Seymour 1956 as cited in Boles 1988).

Water temperature in the upper Sacramento River has been a critical factor leading to the decline of winter-run chinook. Winter-run chinook that spawn below the RBDD at River Mile (RM) 243 typically do not produce offspring due to lethal temperatures (Hallock and Fisher 1985), and winter-run chinook spawning in areas directly above the dam may incur mortality due to lethal temperatures as well.

The problem of inadequate water temperatures has occurred over the past two decades as demand for Central Valley Project (CVP) water has increased. As allocation of water has increased, less water has remained in the Shasta Reservoir during the late summer and fall when it is needed to provide cool water for winter-run chinook eggs and pre-emergent fry. As a result, winter-run chinook mortalities have gradually but clearly increased over time in the upper Sacramento River. Winter-run chinook eggs have suffered mortalities due to elevated water temperature. Due to scattered and limited temperature data, actual estimates of winter-run chinook egg mortalities are not available until 1989, although losses due to warm water temperatures were considered high especially in 1976 (see Figure II-4 in previous chapter). From 1989 to 1991, losses due to temperature have been estimated as: 1) 4-8% in 1989; 2) 20-30% in 1990; and 3) 5-10% in 1991. CVP operations were first modified in 1992 under the ESA, with the issuance of a biological opinion to the USBR (see discussion in following section). Mortalities subsequently declined to an estimated 4.1% in 1992, and then to zero from 1993-1996.

These mortality estimates are considered conservative because they do not include mortality from several diseases which become more virulent at warmer temperatures. *Saprolegnia* is a extremely common fungal disease, which spreads rapidly and suffocates the eggs in a nest. The rate of fungal growth increases exponentially as temperatures increase from the mid-50s to low-60s.

Existing Protective Measures

Maintaining suitable cold temperatures for successful incubation of salmon eggs in the upper Sacramento River has been recognized as essential by fishery and water quality management agencies for at least two decades. In 1975, the State Water Resources Control Board (SWRCB) established a temperature criteria of ≤56°F in its Basin Plan for the Sacramento and San Joaquin River Basins (Basin Plan), to protect salmon spawning and egg incubation in the reach between Keswick Dam to Hamilton City (in compliance with the Federal Clean Water Act (CWA), and designated in Section 1505 of the Fish and Game Code).

This 56°F temperature criteria is measured as daily, average water temperature. As such, the criteria may allow water temperatures to exceed 56°F for some periods during a day, but water temperatures are not likely to exceed 56°F by a large extent or for longer than a few hours. Such temperature fluctuations in the river become dampened within redds, such that inter-gravel water temperatures generally remain cooler than in the water column above. Hence, if the temperature criteria is met in the river, water temperatures should not exceed 56°F within the redds, and suitable water temperatures for salmon incubation should be maintained.

In 1987, the Central Valley Regional Water Quality Control Board (CVRWQCB), NMFS, and CDFG proposed the ≤56°F daily average temperature objective for chinook egg incubation as a waste discharge requirement on the Shasta-Trinity Division of the CVP, under the permitting system known as the National Pollutant Discharge Elimination System pursuant to the Clean Water Act and the Porter-Cologne Water Quality Act. The Shasta-Trinity Division of the CVP was required to achieve the ≤56°F criteria only in the spawning reach between Keswick Dam and Red Bluff. Analysis of past reservoir and river operations indicated that this 60-mile river reach was the extent to which the Shasta-Trinity Division could control temperatures through normal operations of the CVP (U.S. Bureau of Reclamation 1986). This reach typically encompasses ≥95% of the winter-run chinook spawning grounds when delay and blockage problems at RBDD are minimized. When conditions such as drought develop, which are outside the project operators' control, the extent of temperature compliance was permitted to be moved upstream to cover a shorter river reach. The Basin Plan temperature criteria were incorporated into Water Rights Order (WR 90-5), issued by the SWRCB (1990). The ≤56°F temperature criteria was also mandated for all industrial and municipal discharges having the potential to affect temperatures in the spawning area, and downstream as far as Hamilton City.

In 1992, NMFS issued a one-year biological opinion, pursuant to the ESA, on the operations of the CVP and SWP. Following further consultation, a biological opinion was issued in 1993 on the long-term operations of the Federal Central Valley Project and the California State Water Project (CVP/SWP opinion) (National Marine Fisheries Service 1993a). The CVP/SWP opinion similarly specified a daily average temperature of ≤56°F from April 15 to September 30 to protect winter-run chinook egg incubation, and ≤60°F during October to protect post-emergent fry. The river reach for temperature compliance was determined as Keswick Dam to Bend Bridge (located about 40 miles below Keswick Dam). In dry water years, NMFS specified that the 56°F temperature compliance point can be moved upstream as far as Jelly's Ferry (about 35 miles below Keswick Dam) when the USBR's ability to control temperatures is more limited. The impacts of reducing the spawning reach are likely alleviated because the winter-run chinook spawning distribution generally shifts farther upstream under such low streamflow conditions. About 85% to 90% of a year class may migrate to this upper reach if passage at RBDD is unobstructed.

To assure attainment of temperature criteria, NMFS also required a minimum carryover storage of 1.9 million acre-feet (MAF) in all but the driest 10% of the water years to conserve cold water in the reservoir (National Marine Fisheries Service 1993a). This measure was intended to ensure that sufficient water is available for the following summer and early fall period when winter-run chinook are incubating. This operating criteria is estimated to protect 90% of the winter-run chinook spawning population (based upon spawning distribution) during 90% of the water years. It is also expected to avoid losses in consecutive years which are the most damaging to salmon populations.

Operational Management to Achieve Protective Temperatures

During each winter since about 1985, NMFS, CDFG, and the USFWS have attempted to assess runoff forecasts for the upcoming water year to anticipate temperature problems and to develop recommendations for CVP operations. The analysis is based on annual forecasts of precipitation and river runoff. These forecasts are made monthly from December to April of each year. The USBR uses results from a runoff forecast model as input to their CVP Operations Model. The model distributes river flows and reservoir storage to meet water contract demands, Bay/Delta water standards and fishery protections, and any other fish and wildlife flow requirements. The resulting river flow regime and Shasta/Trinity reservoir storage is input to the Sacramento River Temperature Prediction Model, which develops a spatial and temporal table of predicted river temperatures. Although these models are valuable in planning water allocations and achieving temperature criteria, they have inherent weaknesses which limit their accuracy. These weakness include:

Runoff Forecast. Water is allocated to CVP contractors in February, many months before the end of the precipitation season and well before the total amount of water available for delivery is known. Hence, there is an element of risk that Shasta Reservoir inflow will be less than predicted and that end-of-year carryover storage will be less than forecasted. This generally has resulted in high water temperatures in the Sacramento River during the late summer and is a major cause of higher rates of temperature-related mortality to juvenile winter-run chinook.

Central Valley Project Operations Model. The USBR's operations model includes assumptions regarding Sacramento River depletion and accretion rates, which depend primarily on water diversion operations and precipitation, respectively. The USBR develops estimates of depletion rates over the summer based on cropping patterns and land development in the region. However, these estimates are frequently in error by 20% or more. As a result, the USBR may compensate by releasing additional water from Shasta Reservoir, which, in turn, may result in lower end-of-year carryover storage and higher than predicted water temperatures during September and October. This deficiency occurred in 1992.

Predictive Temperature Model. The USBR's predictive temperature model uses average ambient air temperatures to predict average monthly water temperatures. In the event ambient air temperatures exceed average conditions, warming of water as it passes through Keswick Reservoir could be significantly underestimated. Also, average monthly water temperatures do not reflect the trend or magnitude of temperature fluctuations occurring within a month and may underestimate the potential for temperature-induced mortality of eggs and fry.

Chinook Salmon Temperature-mortality Model. Prior to ESA listing of winter-run chinook, the USBR used the predictive temperature model in combination with a chinook salmon temperature-mortality model to predict winter-run chinook mortality. Specifically, the USBR would allocate water to its contractors, then analyze how to use the remaining water to minimize winter-run chinook mortalities using the chinook salmon model. The fishery agencies, on the other hand, focused on achieving the ≤56°F temperature criterion needed for successful spawning and incubation. With issuance of the CVP/SWP opinion, the USBR now operates to achieve the 56°F temperature criteria, with variances on the river compliance point depending on water year type.

The chinook temperature-mortality model could be used in the future in the extreme case when the 56°F temperature criteria cannot be met, and managers need to determine how to optimize winter-run chinook survival given the limited water resources. However, there would be substantial risk involved because of several model limitations. First, the chinook temperature-mortality model predicts temperature-related losses of eggs and larvae based on hypothetical winter-run chinook spatial and temporal spawning distributions. Actual spawning distributions cannot be used because water allocation decisions are made in February, long before the winter-run chinook spawning season. Higher losses can result if actual spawning distributions are different. Second, the survival model does not consider the effect of warm water on the prevalence of disease organisms.

Finally, the USBR may modify its proposed operation of the RBDD during the agricultural season, by adding an intermittent closure of the dam. Such a closure would likely shift the spawning distribution of winter-run chinook further downstream because the closure of the dam causes delay and blockage of migration. This shift would likely increase the mortality above that predicted by the chinook model.

Evaluation of Existing Protective Measures

The protections provided under the NMFS CVP/SWP Biological Opinion are sufficient to prevent jeopardizing winter-run chinook with extinction. However, further protections are needed to recover the population. Specifically, more flexibility is needed for attaining temperature control in the upper Sacramento River. The USBR's temperature operation plans, based on the various models, usually offer limited flexibility and often adversely affect winter-run chinook eggs, juveniles, and adults. Temperature-related loss of eggs and fry have often been higher than predicted by the USBR's survival model.

Proposed CVP operational scenarios in years of critical and extremely critical hydrology could weaken the associated winter-run chinook year class. Generally, the winter-run chinook ocean population is comprised of three year-classes, which contribute 2-, 3-, or 4-year-old fish to the annual spawning population. The loss of a single year class would likely result in reduced spawning stock and low recruitment in each of the second, third, and fourth subsequent years. During prolonged periods of drought, year classes could be sequentially weakened to the point that total population levels for successive year classes would not recover.

Adverse Temperature Conditions: Middle and Lower Sacramento River, and Delta
(Below RBDD and downstream through the Delta)

In general, water temperatures in the middle and lower Sacramento River reaches are influenced by flow releases from Shasta Reservoir. They are also affected by: 1) flow accretions and depletions, 2) weather, 3) agricultural and municipal discharges, 4) reduced riparian habitat, and 5) overall modification of the hydrologic system for flood control, reclamation and navigation, which has altered the configuration of channels.

Water temperatures in the middle Sacramento River typically exceed 60°F from July through September, and in drier years, often exceed 66°F (Turek 1990). Temperatures normally become satisfactory over the late fall and winter period, until April when temperatures above 60°F begin to recur, especially in drier years. Water temperatures can reach 65°F at Freeport in April and up to 69°F in May (BioSystems Analysis 1992). During the 1987-1992 drought, temperatures always exceeded 65°F in May and nearly always exceeded 68°F (at City of Sacramento) (unpublished water temperature data for Sacramento Water Treatment Facility).

Recent research has provided evidence that spring to early summer water temperatures of the Sacramento River may have risen from 2°F to 7°F since the late 1970s (Mitchell 1987, Reuter and Mitchell 1987). Specifically, average monthly river temperatures at Red Bluff (RM 243), Butte City (RM 169) and Grimes (RM 125) increased about 2 - 3.5°F during April through June from the pre-drought years (pre-1976) to the post-drought years (post-1977). At Sacramento, the average monthly temperature during these same months increased by about 4 to 5° F from 1965-1975 to 1978-1985. Upstream of the cooling influence of the American River, the magnitude of increase was even greater (about 3.5-7°F). The temperature increase in the upper Sacramento River (Red Bluff, Butte City, Grimes) can be explained to a large extent by streamflow reductions in post-drought years. However, at Sacramento, higher post-drought water temperatures and cooler pre-drought temperatures occurred at equal flows. This temperature difference, suggests that factors other than flow are responsible for higher temperatures in recent years (Reuter and Mitchell 1987), which may include agricultural and municipal drainage and loss of riparian habitat.

Effects on Winter-run Chinook

A daily average temperature of 60°F is considered the upper temperature limit for juvenile chinook growth and rearing, whereas warmer water temperatures are likely to lead to physiological stress and mortality. Juvenile chinook appear to prefer temperatures between 45°F and 58°F (Brett 1952), and experience optimum growth between 54°F and 60° F (Rich 1987). Impacts of warmer temperatures include sublethal stress which leads to reduced growth, disease outbreaks, and other problems, and at higher temperatures, death. Rich (1987) found that at water temperatures between 60°F and 63.5°F, juvenile chinook salmon experience low sub-lethal chronic stress. Above 66°F, Rich (1987) found that juvenile chinook salmon showed a decline in growth rate. Marine and Cech (1992) found that at temperatures between 62.6°F and 68°F, juvenile chinook became fatigued, disoriented, and exhibited modified behavior, which made them more susceptible to predation. Brett (1952) found that juvenile chinook begin to experience immediate mortality at temperatures of 75°F and higher.

Juvenile winter-run chinook are most abundant in the middle and lower river reaches during the winter when average temperatures are typically less than 60°F. However, the earliest emigrating winter-run chinook (mid-July to September), and later emigrating juveniles (April-May) may be exposed to temperatures above 60°F in the river. In the Delta, water temperatures probably do not affect juvenile winter-run chinook substantially until the spring when temperatures increase (between April and June).

Water temperatures are normally satisfactory during the adult winter-run chinook upstream migration, until April or May. Later migrating adults may experience water temperatures up to 65°F-69°F in the lower Sacramento River, which may reduce their energy supplies for spawning activities; cause pre-spawning mortality; reduce gamete viability; and partially or fully block their upstream migration. In studies of fall-run chinook, adults began to experience physiological stress when exposed to water temperatures in the range of between 59°F to 68°F for prolonged periods (Marine 1992). Poor egg viability has also been found in adult fall-run chinook held in hatcheries at temperatures greater than 60°F (Hinze 1959). In the San Joaquin River, adult chinook migration ceased at temperatures above 70°F, then resumed when temperatures decreased to 65°F (Hallock et al. 1970). Diseases in adults also become exacerbated at elevated water temperatures.

Existing Protective Measures

The SWRCB's Basin Plan outlines a temperature criteria of ≤56°F from Keswick Dam to Hamilton City, and ≤68°F from Hamilton City to the I Street Bridge (city of Sacramento), during periods when temperature increases are detrimental to the fishery. The plan also specifies that dischargers may release water at temperatures up to 5°F higher than the Sacramento River, until the maximum temperature criteria is reached.

Attainment of the ≤56°F criterion from RBDD to Hamilton City would provide acceptable temperatures for winter-run chinook. However, there are no practical reservoir operations that can reasonably be considered for controlling temperature between RBDD and Hamilton City, or downstream to the city of Sacramento, or the Delta. Therefore, it becomes important to control river temperatures through other measures such as minimizing the effects of thermal discharges from agricultural and municipal wastewater, and longer-term measures such as restoration of the riparian forest.

The 68°F temperature objective for the river reach between Hamilton City and the I Street Bridge is too high to protect juvenile and adult winter-run chinook. The 68°F criteria, coupled with the 5°F maximum temperature increase above ambient river temperature, allows dischargers to release effluent at temperatures potentially between 60° and 68°F. Such high temperatures would be most likely to affect early and late migrating juvenile winter-run chinook, and late migrating adults.

The Basin Plan objectives apply to municipal and industrial dischargers, but do not apply to agricultural discharge, which instead is regulated as non-point source discharge. However, the largest source of thermal discharge to the lower river is the agricultural discharge of the Colusa Drain at Knights Landing. Drain flows often exceed 2,000 cfs with water temperatures exceeding 80°F, while typical summer flows are 15,000 cfs with temperatures of 68°F. Warm water is released from the drain to the river mainly from April through June, which may affect late-emigrating winter-run chinook and late migrating adults. This regulatory measure is clearly inadequate to protect winter-run chinook from elevated temperatures that result from agricultural discharge.

Conversely, other recent regulatory measures for the Delta have provided winter-run chinook some improved protection from high temperatures. The Principles for Agreement on Bay-Delta Standards between the State of California and the Federal Government (Principles) now requires that the gates on the Delta Cross Channel (DCC), which connects the Sacramento River to the lower Mokelumne River, remain in the closed position from February 1 through May 20.[1] This action should help to reduce the number of juvenile winter-run chinook that are diverted in the spring into the central and southern Delta, where water temperatures are typically higher than in the main stem Sacramento River.

[1] NMFS in their 1993 Biological Opinion for the Central Valley and State Water Projects required the Delta Cross Channel gates to be closed from February 1 through April 30.

Adverse Flow Conditions: Upper Sacramento River
(Keswick Dam to RBDD)

Large flow fluctuations are the main concern regarding adverse flow conditions in the upper Sacramento River. The largest and most rapid flow reductions have occurred during the irrigation season when flashboards at the antiquated Anderson-Cottonwood Irrigation District (ACID) dam on the Sacramento River need adjustments. Under a water rights settlement contract (contract No. 14-06-3346A, June 6, 1967), CVP operators are required to reduce Sacramento River flows for ACID dam operations. In the past, the District has indicated that 5,000 cfs is the maximum flow at which their personnel can safely install or remove the flashboards. To accommodate these adjustments, Sacramento River flows at times have been decreased by one-half or greater, over the course of merely hours.

Effects on Winter-run Chinook

ACID dam flashboard adjustments have typically involved the reduction of Sacramento River flows in the late summer and fall, during the incubation and rearing period of winter-run chinook. In years of full water deliveries by the CVP, flows have been reduced from levels of 10,000-14,000 cfs to a level of 5,000 cfs. As a result, redds constructed during high flows have become dewatered. Eggs and larvae in redds dewatered for an extended period can suffer 100% mortality, particularly during hot summer days. Eggs and larvae within partially dewatered redds may also experience mortality because flows through the gravel substrate are reduced.

Flow reductions may also result in the stranding of juvenile winter-run chinook. Winter-run chinook fry prefer shallow nearshore areas with slow current and cover during the late summer and fall. Large stream fluctuations may strand these fry in shallow pools and side channels, or completely dewater them (California Department of Fish and Game 1990). When trapped in shallow pools, winter-run chinook fry may be subject to lethal water temperatures, avian predators, and other adverse conditions.

Existing Protective Measures

Under the CVP/SWP Biological Opinion, the USBR must conduct any flow reductions, between July 1 and April 1, at night and at specific rates to minimize or eliminate the potential for strandings. Conducting flow reductions at night should help minimize strandings because salmon fry tend to move downstream at night, and will move from nearshore areas to the mid-channel.

The flow reduction rates specified in the opinion are divided into several intervals. For flow reductions to a level of 6,000 cfs, flows must not be decreased by more than 15% each night and not by more than 2.5% in a one-hour period. For reductions ranging between 5,999 cfs to the minimum of 3,250 cfs, flows were required to be reduced at lower rates because juveniles are more susceptible to stranding at these flows, particularly in side channels with shallow depressions and broad flat-gradient nearshore areas. However, recently ACID entered into an agreement with the USBR to not call for flow reductions below 6,000 cfs after the flashboards are installed. This measure should reduce the potential for strandings and dewatering although clearly does not eliminate the problem.

In addition, the CVP/SWP Biological Opinion requires the USBR to maintain a minimum flow releases of 3,250 cfs from Keswick Dam from October 1 through March 31 to provide safe rearing and downstream passage for juvenile winter-run chinook. This minimum flow should adequately protect winter-run chinook when runoff and storage conditions are low. However, flows between 5,000 and 5,500 cfs from October through March would provide a more suitable river environment, given that runoff and storage conditions are sufficient for future temperature control. Such flows would increase the length of river with suitable temperatures, provide extensive nearshore rearing habitat, improve riparian growth bordering the river, and increase aquatic insect production.

However, in the absence of these higher, minimum flows (5,000-5,500 cfs), some flow reductions in the fall are important to prevent early spawning fall-run chinook redds from using areas that will subsequently become dewatered. Flows during the summer and fall are generally at least 6,000 cfs (monthly average), under most water year types, in order to maintain cool temperatures for winter-run chinook. As a result, fall-run chinook may build redds at these higher flows. Flows are then substantially reduced over the winter to reserve water for storage. As a result, fall-run chinook redds constructed during the higher flows may become dewatered over the winter. A balance is needed to adjust flows to protect naturally spawning fall-run chinook as well.

Adverse Flow Conditions: Middle and Lower Sacramento River
(Below RBDD)

Flood control structures on the Sacramento River are designed to divert Sacramento River water from the main river during major flood events into the Butte Creek basin, and the Sutter and Yolo bypasses. Depending on flow levels, the flood control system can divert as much as 4 to 5 times more flow down the leveed bypasses than remains in the main river channel (Resource Consultants & Engineers and Jones & Stokes 1994). For example, the proportion of monthly Sacramento River flow diverted into the Sutter Bypass during 1941-1991 varied from 0% for drier years to over 70% for wetter years.

Effects on Winter-run Chinook

Juvenile winter-run chinook migrating down the Sacramento River are susceptible to diversion into the bypasses during major storm events. Juvenile chinook salmon were observed in field surveys of Sutter Bypass during flood events in February through April, 1993 (Jones & Stokes 1993a) including juveniles in the winter-run chinook size range. In April 1996, an estimated 10,860 juvenile spring and fall-sized chinook salmon were captured during the seining of about 1 acre of the Sacramento Bypass (Jones & Stokes 1996). Although survival rates associated with these migration routes are unknown, juveniles diverted into flood bypasses may be subject to potential migration delays or entrapment as flood flows recede, as well as predation.

Studies of the Sutter Bypass indicated the greatest proportion of water is diverted during December through March, with peak diversion during February (Jones & Stokes 1993a). This closely corresponds with the range and peak migration patterns of juvenile winter-run chinook. However, the probability of a substantial proportion of flow being diverted may be relatively low. During February, diversion of more than 20% of the flow could be expected to occur about 20% of the time (Jones & Stokes 1993a).

Adult winter-run chinook migrating upstream may also enter these bypasses, where their migration may be delayed or blocked by control structures in the upper end of the bypass channels. To date, there have not been any measures implemented to protect winter-run chinook from entrainment into the flood bypasses (i.e. installation of fish ladders, barrier placement).

Adverse Flow Conditions: Delta Hydrodynamics

The Delta is legally defined in the California State Water Code (Section 12220) and roughly corresponds to the triangular area determined by the city of Sacramento, the mouth of the Stanislaus River, and Pittsburg (Figure III-1). The northern Delta is that portion dominated by waters of the lower Sacramento River. The western Delta is the area near the confluence of the Sacramento and San Joaquin rivers and is subject to the greatest tidal effects. The southern Delta is dominated by San Joaquin waters; the eastern Delta is dominated by Cosumnes and Mokelumne rivers; and the central Delta is poorly defined but includes the myriad of intricate waterways between the Sacramento River and the lower San Joaquin River.

The Sacramento River provides most of the water flowing into the Delta, whereas the San Joaquin River rarely contributes more than 20% (Herbold and Moyle 1989). With the operation of upstream reservoirs and the State and Federal Pumping plants in the Delta, the Delta is now regulated such that the seasonal distribution of flows is different from historic patterns. In general, flows have become reduced in the spring and early summer for storage purposes, and higher in the late summer and fall to prevent salt water intrusion. Overall, water management has resulted in reduced natural variability in the system creating more uniform flows.

Mean monthly river flows for the Sacramento and San Joaquin Rivers from October 1955 through October 1994 exhibit typical peak flows during the winter with low flows in the summer

(Figure III-2). The San Joaquin River flow is measured at Vernalis and the Sacramento River flow is measured at Freeport. (The data are from DAYFLOW databases which uses Sacramento River flows at I Street up to October 10, 1979, and then Freeport flows thereafter. The two are not distinguished in the databases.) During the period of record, the annual export of water from the Delta has increased significantly (Figure III-3). The four largest export facilities include the State Water Project, Central Valley Project, Contra Costa Canal, and the North Bay Aqueduct pumping facilities.

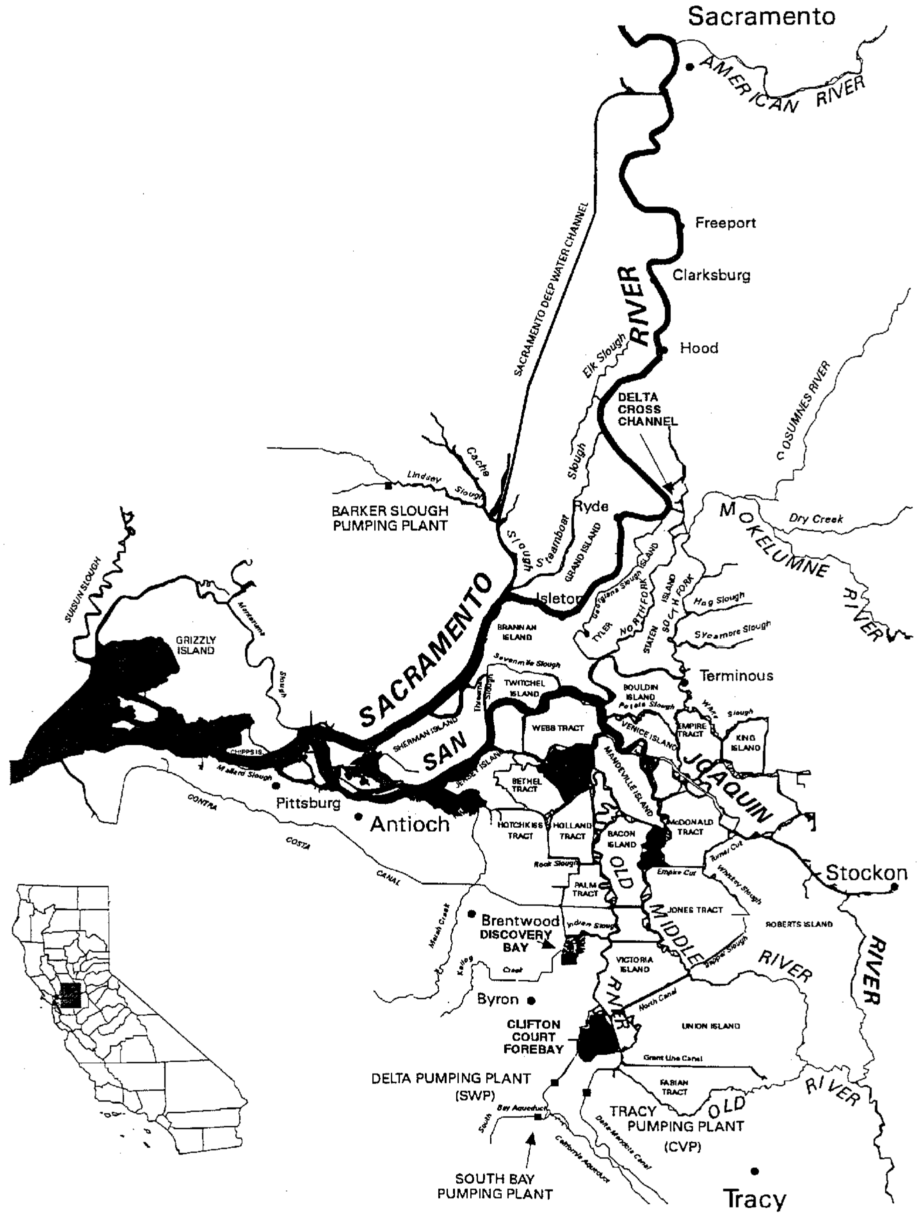
State and Federal water project operations in the Delta can also influence the direction of net channel flows. During winter and spring, when the Sacramento and San Joaquin rivers are typically at their peak discharge, net flow moves downstream toward the western Delta. As the quantity of water exported increases relative to Sacramento River outflow, Sacramento River water can then be drawn around Chipp's Island (in the western Delta) and upstream through the lower channels of the San Joaquin River, creating what is termed "reverse flow" conditions. This reverse flow moves the net flow of water easterly in the San Joaquin River, and then to the south via Old and Middle Rivers, towards the pumps. These reverse flows are especially exacerbated during periods of high CVP/SWP pumping. In addition, flow patterns are altered when the Delta Cross Channel (DCC) is opened, and a proportion of Sacramento River water is diverted through the DCC. This Sacramento River water is conveyed in a southerly direction to the CVP and SWP pumping plants. During the period of record, the mean monthly QWEST, or San Joaquin River flow estimate, past Jersey Point has changed from infrequent period of negative QWEST values and high values of QWEST to tightly controlled values that are often negative (Figure III-4). This latter condition has been prevalent since the 1986 water year.

The amount and direction of San Joaquin River flow past Jersey Point is indicative of the water balance about the central and southern Delta. In particular, net reverse flow past Jersey Point indicates that higher salinity water is being drawn into the interior Delta as a result of high depletions and exports with respect to stream inflows. QWEST is calculated as: Eastern Delta Inflow plus Delta Cross Channel and Georgiana Slough flow minus Total Delta Exports and Diversion/Transfers minus 65% of the net Delta channel depletions in the central and southern Delta (DAYFLOW definition).

In addition, the mean monthly export/inflow ratio between October 1955 and October 1994 has increased with some of the highest values occurring in the late 1980s (Figure III-5). This index is calculated as: State Water Project plus Central Valley Project divided by Total Delta Inflow (sum of Sacramento River, Yolo Bypass, San Joaquin River, and Miscellaneous East Side Stream flow).

Another measure of the effect of in Delta depletions and Delta export facilities is the mean monthly percent diverted (Figure III-6). This value is calculated to quantify the portion of Delta

Figure III-1. Map of the Sacramento-San Joaquin Delta.



water diverted for internal use and exports and is: Total Inflow minus Total Outflow divided by Total Inflow multiplied by 100. Likewise, mean monthly Delta Cross Channel and Georgiana Slough flows are a measure of Delta water operations (Figure III-7). To obtain an approximation for cross-Delta flow (north Delta water reaching the central and southern Delta

Figure III-2. Mean monthly flow for the Sacramento River measured at Freeport and the San Joaquin River measured at Vernalis, October 1955 through October 1994.

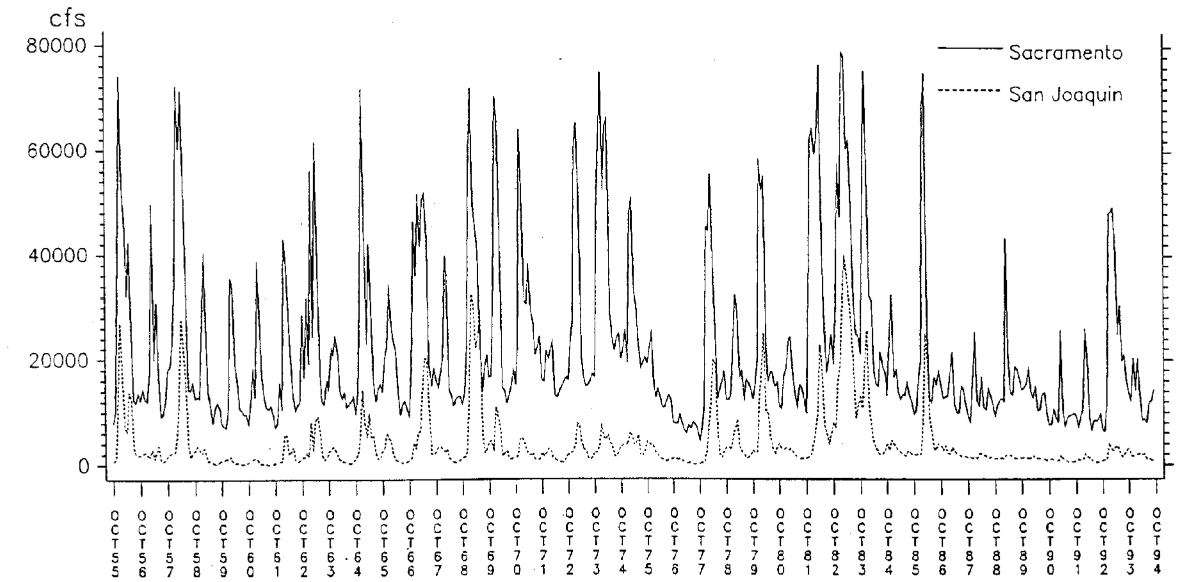


Figure III-3. Total annual export at the State Water project, Central Valley Project, Contra Costa Canal, and the North Bay Aqueduct, 1956 through 1994.

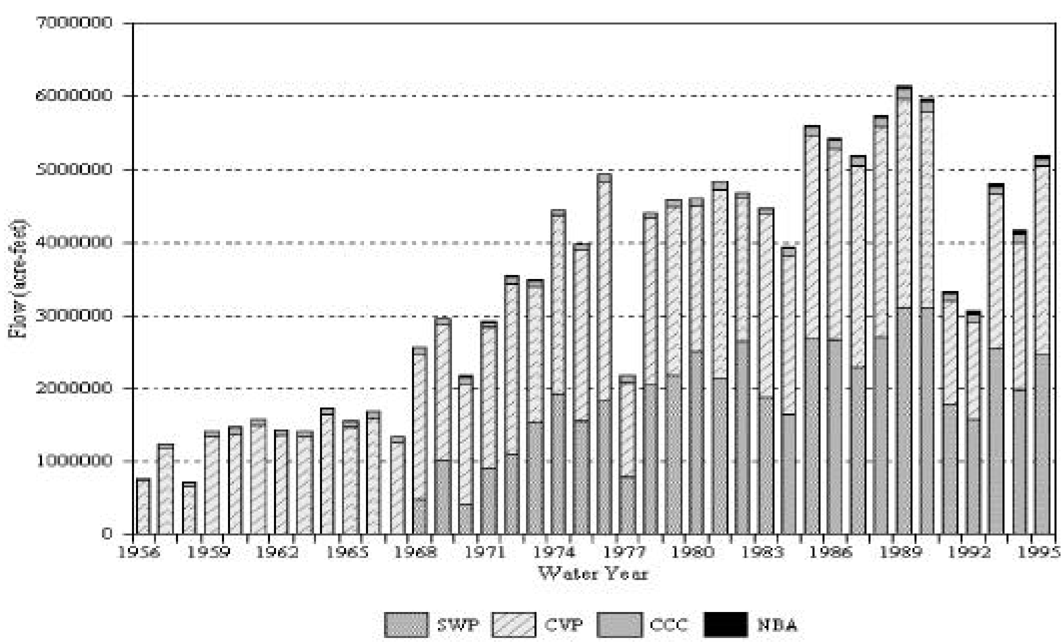


Figure III-4. Mean monthly QWEST index from October 1955 through October 1994.

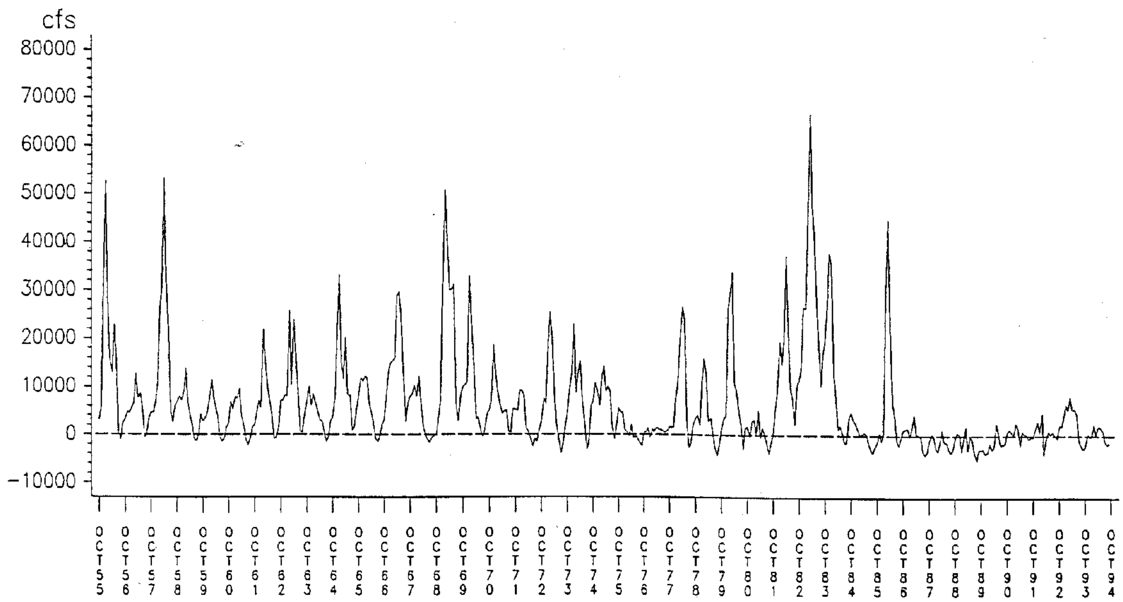


Figure III-5. Mean monthly export/inflow ration from October 1955 through October 1994.

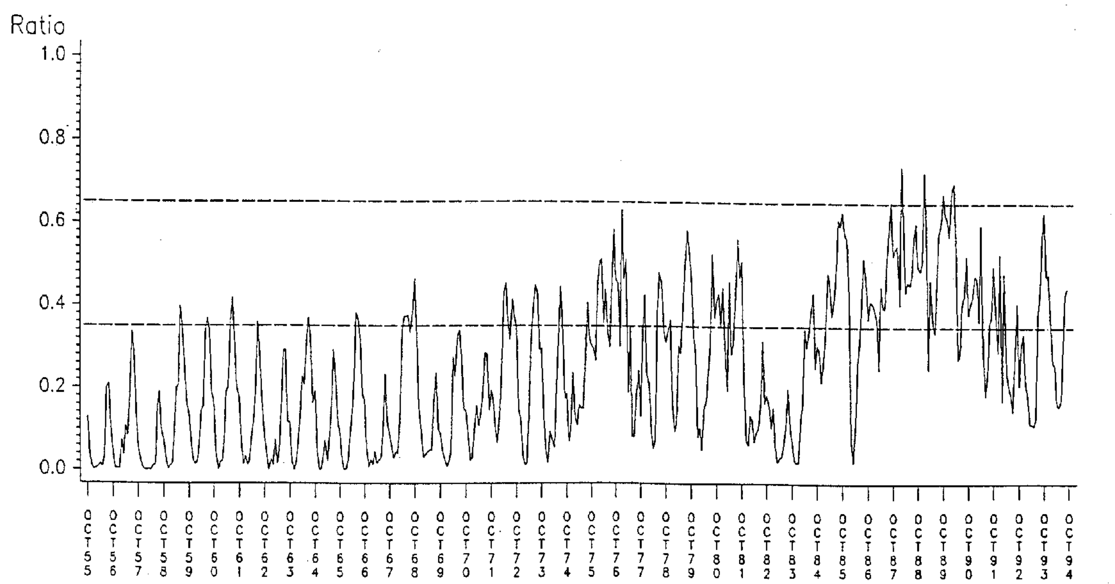


Figure III-6. Mean Monthly percent of water diverted in the Delta from October 1955 through October 1994.

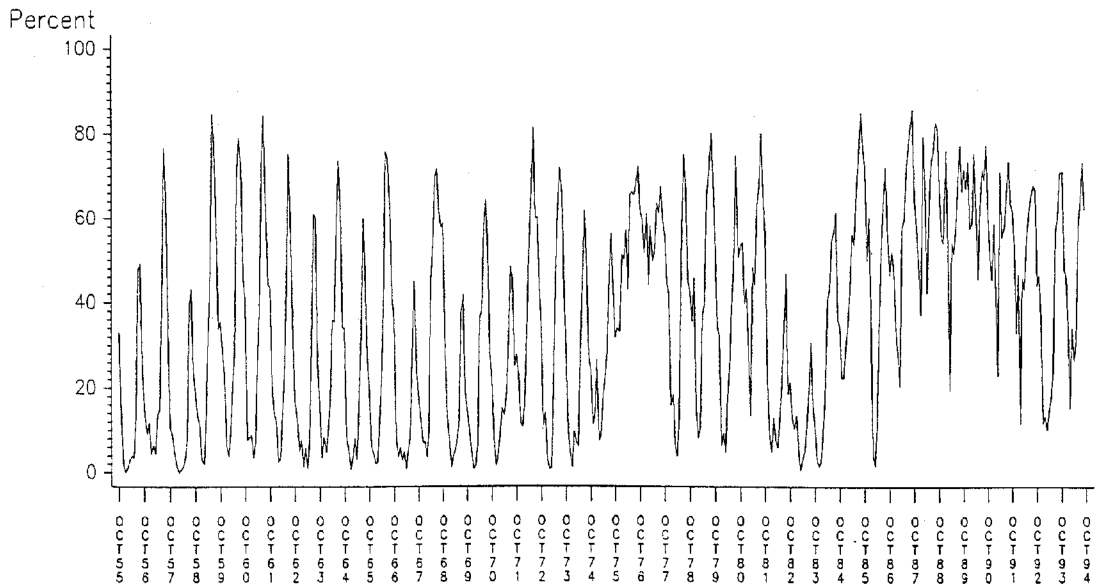
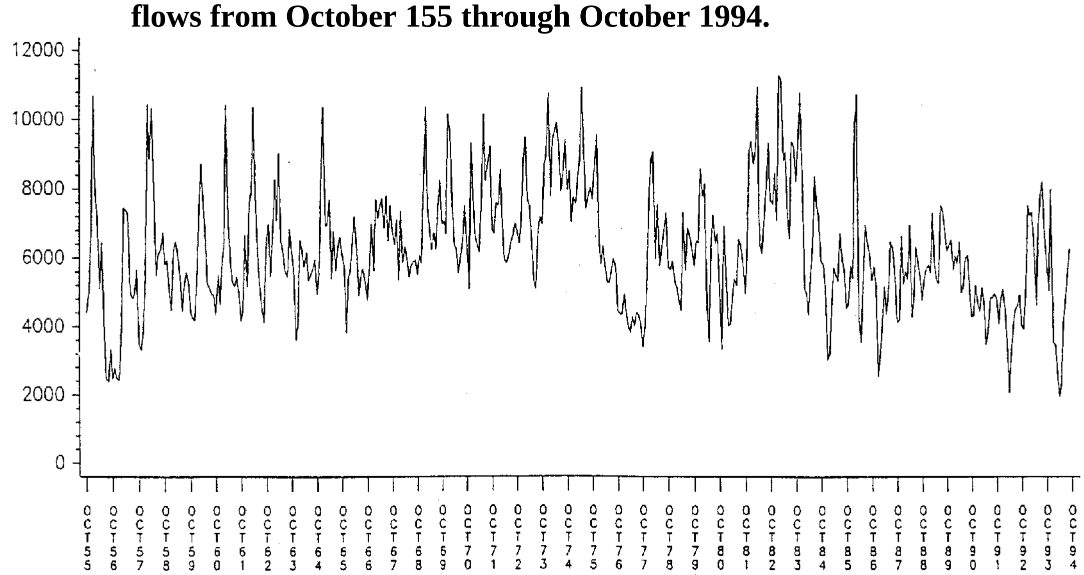


Figure III-7. Mean monthly calculated Delta Cross Channel and Georgiana Slough flows from October 155 through October 1994.



channels), the amount of water reaching the Mokelumne River system and Georgiana Slough must be known. Because there are no streamflow gaging stations on either channel, empirical relationships have been developed to estimate Delta Cross Channel and Georgiana Slough flow based on Sacramento River flow measured at I Street Bridge in Sacramento. There are three relationships depending on the gate positions: 1) both gates open, 2) one gate open, and 3) both gates closed.

Effects on Winter-run Chinook

As flow has become highly manipulated in the Delta, a broad scope of direct and indirect impacts has likely diminished winter-run chinook survival. These problems are primarily related to changes in hydrology, whereby the timing, quantity, export and distribution of water flow into and through the Delta have been altered. The primary factors causing salmon mortality in the Delta are considered to be: 1) the diversion of winter-run chinook from the main stem Sacramento River into the central and south Delta where environmental conditions are poor; 2) reverse flow conditions created by pumping; and 3) entrainment at CVP and SWP pumping plants and associated problems in Clifton Court Forebay. In addition, poor food supply may limit the rearing success of winter-run chinook. There are other related water management projects which may adversely affect winter-run chinook, including barriers at Grant Line Canal, the head of the Old River, Old River at Tracy, and the Middle River.

The following discussion on the impacts of Delta flow manipulation on winter-run chinook survival is primarily based on information derived from mark (coded-wire-tag, CWT) and recapture studies conducted with fall-run chinook hatchery smolts.[2] Much of this information can be reasonably inferred to winter-run chinook, however, there are notable differences in the juvenile life histories of the two populations, which include: 1) the majority of winter-run chinook smolts are in the Delta in the winter and early spring when temperatures are lower than for fall-run chinook smolts; and 2) winter-run chinook smolts enter salt water at a larger size than fall-run chinook smolts (average of about 118 mm for winter-run chinook, versus an average of about 85 mm for fall-run chinook). Results from recent mark/recapture studies with late-fall-run chinook may better reflect the responses of juvenile winter-run chinook to conditions in the Delta. Both late-fall-run and winter-run chinook occur in the Delta during the winter when temperatures are cooler, and late-fall chinook emigrate to the ocean at a size similar to winter-run chinook smolts.

In addition, it is important to recognize that results from mark/recapture studies using hatchery fish may not completely reflect the natural population. Hatchery and wild fish are reared

[2] Coded-wire-tags are 1 mm sections of stainless steel wire marked with a discreet binary code that identifies the time and location that chinook salmon are released. Coded-wire-tagging is a standard practice used along the Pacific Coast to monitor salmon populations.

under different conditions, which may influence their survival rates in the river. However, it seems reasonable that the relative differences in survival of smolts migrating through different waterways in the Delta are similar for natural and hatchery fish.

Diversion into Central Delta. Historically, juvenile chinook naturally migrated from the Sacramento River into the Central Delta via Georgiana and Three Mile sloughs, in direct proportion to the volume of water transporting them, which was estimated at about 20% (March 1948) (Erkkila et al. 1950). With construction of the DCC, a much greater proportion of Sacramento River water could be diverted into the central Delta. As much as 70% of Sacramento River flow (at Walnut Grove) may be diverted into the central Delta with the DCC opened (whereas only 20-30% is drawn in with the DCC gates closed) (U.S. Fish and Wildlife Service 1987a). The proportion of Sacramento River water diverted will vary with flow, such that higher proportions of water are diverted at lower Sacramento River flows and visa versa.

Smolts are likely influenced by these flow patterns, such that greater numbers of salmon move into the central and south Delta with the higher proportion of flow moving to those Delta areas. Mark and recapture studies with fall-run chinook suggest that salmon smolts entering into the central Delta via the DCC and Georgiana Slough have a much lower index of survival than those remaining in the main stem Sacramento River (U.S. Fish and Wildlife Service 1992a).[3] On average, these studies showed that smolts survived about 3.4 times greater to Chipps Island when released below the open DCC and Georgiana Slough, than above the channels (Table III-1). Similar experiments with the DCC closed found that smolts released below the closed DCC and Georgiana Slough survived about 1.3 to 2.4 times better (average 1.6 times) than those released above (Table III-1). Analogous results were also observed for releases, using an index of survival based on recoveries of the marked fish as adults in the ocean fishery. However, comparison of survival indices in Table III-1 do not yield statistically significant differences in survival (2-tailed t-test, p=0.55). Therefore, results are not conclusive but indicate an important potential for reduced survival through diversion into the Delta.

In conjunction with the above studies, additional marked smolts have been released directly into the central Delta: in the north and south forks of the Mokelumne River between 1984 and 1986, and in the lower Mokelumne River in 1983 (U.S. Fish and Wildlife Service 1987a). Survival indices of fish released directly into the central Delta were lower than fish released in the main stem Sacramento River below the DCC and Georgiana Slough. However, survival indices were similar to marked fish released directly into the Central Delta and marked fish released above the channels with the DCC gates open.

[3] Studies were conducted between 1983 and 1989, using Feather River hatchery fall-run chinook.

Table III-1. Comparisons of the Survival Indices for Coded-wire Tagged Fall-run Chinook Salmon Smolts Released in the Sacramento River above and below the Delta Cross Channel and Georgiana Slough between 1983 and 1989.

Cross Channel Operation	Year	Above (Walnut Grove)		Below (Ryde)		Ratio of Below/Above
		Survival Index	Temperature at Release (°F)	Survival Index	Temperature at Release (°F)	
Open	1984	0.70	66	0.73	66	1.04
	1985	0.34	64	0.77	66	2.27
	1986	0.37	74	0.68	74	1.84
	1987	0.41	67	0.88	64	2.15
	1988	0.73	61	1.27	61	1.74
	1988	0.02	76	0.34	74	17.0
	1989	0.84	61	1.20	62	1.43
	1989	0.35	69	0.48	67	1.37
	1989	0.21	71	0.16	73	0.76
						Average: 3.29
Closed	1983	1.22	60	1.39	61	1.14
	1987	0.66	67	0.84	67	1.27
	1988	0.68	62	0.93	63	1.37
	1988	0.17	73	0.40	75	2.35
						Average: 1.53

Note: "Above" indicates fish released at Courtland, 3.5 miles above Walnut Grove, and "Below" indicates fish released at Ryde, 3.0 miles below Walnut Grove.

This differential mortality between fall-run chinook smolts released in the central Delta versus those released in the main stem has been verified by further studies. Paired groups of fall-run chinook were released at Ryde (main stem Sacramento River below Georgiana Slough and DCC) and in Georgiana Slough in the spring of 1992 through 1994 (U.S. Fish and Wildlife Service 1993a). At temperatures between 58°F and 65°F, survival of fish released at Ryde was about 3.7 times greater than for corresponding groups of fish released into Georgiana Slough. At 67°F, the difference was about 8 times greater (Table III-2).

Similar experiments were conducted in 1993-1996 using Coleman hatchery late-fall-run chinook smolts released at Ryde and Georgiana Slough at temperatures at cool water temperatures (Table III-3) (U.S. Fish and Wildlife Service, unpublished data). The results showed that late-fall-run chinook smolts survived about 4 times better when released in the main stem at Ryde than those released into Georgiana Slough, surprisingly similar to results from the fall-run chinook studies. It appears that the larger size of the late-fall-run fish and lower water temperatures did not reduce the differential mortality of late-fall-run chinook smolts that entered the central Delta. Thus, the movement of juvenile chinook salmon into the central Delta has been demonstrated as detrimental to both fall-run and late-fall-run chinook survival, and is assumed to be detrimental to winter-run chinook as well.

One interesting result was obtained with the late-fall chinook release in 1996 where three concurrent releases were made at Ryde, Georgiana Slough and above the DCC. Late-fall smolts released above the DCC actually survived 0.85 times better than those released at Ryde (index above was 0.78; index below at Ryde was 0.66), while survival in Georgiana Slough was still relatively low (0.17).

Table III-2. Comparison of 1992-1994 coded-wire tag survival indices for groups of fish released at Georgiana Slough and Ryde and the ratio of survival between the two paired groups.

Date	Survival Index at Ryde	Temperature at Release (°F)	Survival Index at Georgian a Slough	Temperature at Release (°F)	Ryde/Georgiana Slough Ratio
4/06/02	1.36	64°	0.41	64°	3.3
4/14/92	2.15	63°	0.71	64°	3.0
4/27/92	1.67	67°	0.20	67°	8.3
4/14/93	0.41	58°	0.13	58°	3.2
5/10/93	0.86	59°	0.29	65°	3.0
4/12/94	0.198	62.5°	0.054	62°	3.7
4/25/94	0.183	62°	0.117	62°	1.5
					Average: 3.7

Table III-3. Comparison of 1993-1996 coded-wire tag survival indices for groups of late-fall chinook released at Georgiana Slough and Ryde and the ratio of survival between the two paired groups.

Date	Survival Index at Ryde	Temperature at Release (°F)	Survival Index at Georgiana Slough	Temperature at Release (°F)	Ryde/Georgiana Slough Ratio
12/2/93	1.91	51°	0.28	51°	6.8
12/5/94	0.57	50.5°	0.16	50°	3.6
1/4/95	0.33	54°	0.12	54°	2.8
1/10/96	0.66	51°	0.16	52°	4.1
					Average: 4.3

Smolts also move into the central Delta via Steamboat and Sutter sloughs. Limited CWT results from fall-run chinook found that in two out of three release groups, smolts survival was similar between fish released into these sloughs and those released down the main stem Sacramento River, below the DCC and Georgiana Slough (Table III- 4) (U.S. Fish and Wildlife Service 1990).

Table III-4. Survival indices for coded-wire tagged juvenile fall-run chinook released into Sutter and Steamboat sloughs, and at Ryde on the main-stem Sacramento River, from 1988-1990.

Year	Sutter Slough	Steamboat Slough	Ryde (mainstem)
1988	--	0.38	0.34
1989	1.11	0.91	0.16*
1990	0.75	1.05	1.25

*The survival index was unusually low potentially due to the high temperature at release (73°F), or the fact that these fish were released on an incoming tide which could have subjected them to diversion at Walnut Grove in the DCC or Georgiana Slough (U.S. Fish and Wildlife Service 1989).

The sources of mortality for fish entering into the central Delta are likely a combination of adverse conditions resulting from: CVP and SWP operations; poor riparian, tidal marsh and shallow water habitat conditions; predation; and a longer migration route to the ocean (U.S. Fish and Wildlife Service 1992a; IEP Estuarine Ecology Project Work Team 1996). The central Delta also has a greater number of agricultural diversions and more complex channel configurations than the main stem Sacramento River. The channel complexity, in conjunction with the tidal and reverse flow patterns, likely delays migration to the ocean, which increases the length of time that smolts are exposed to adverse conditions. Also, susceptibility to diversion into Clifton Court Forebay or entrainment at the CVP and SWP pumping plants is more likely for fish migrating through the central Delta than for those migrating down the main stem Sacramento River (U.S. Fish and Wildlife Service 1992a). Historically, the central Delta was probably beneficial for rearing juvenile chinook salmon, including winter-run chinook, due to the extensive acreage of tidal marsh habitat and its associated nutritional and cover benefits. However, degradation of central Delta waterways have led to adverse conditions for the rearing and migration of winter-run chinook.

Reverse flow conditions. The mechanism by which flow conditions, altered by pumping operations, affect survival of juveniles in the Central Delta are poorly understood. One mechanism that has been advanced is reverse flow. That is, juveniles that move into the central Delta and reach the confluence of the Mokelumne River with the lower San Joaquin River are exposed to a net reverse flow. These reverse flows influence fish movement such that juvenile salmon move from the lower San Joaquin into the complex system of south Delta waterways where predation rates are assumed to be high, and then towards the pumping plants (U.S. Fish and Wildlife Service 1987a, 1992a). Results from mark/recapture studies of fall-run chinook released into the lower San Joaquin River at Jersey Point (between Jersey and Sherman islands) indicate that survival of smolts migrating through the lower San Joaquin River was decreased during periods of net reverse flows.[4]

Juveniles that remain in the main stem Sacramento River may reach Chipps Island and then become influenced by reverse flows, which move them into the lower San Joaquin River, and down into the south Delta waterways. These fish are probably influenced to a much smaller degree than fish entering the central Delta farther upstream (via the DCC and Georgiana Slough). Since 1978, only a few marked fall-run smolts released into the Sacramento River at Ryde (below DCC and Georgiana Slough) have been observed at the pumping plants salvage facilities. Conversely, up to several hundred marked smolts have been observed from those releases made into the central Delta (U.S. Fish and Wildlife Service 1987a). Thus, smolts exposed to reverse flow via their potential movement through Three Mile Slough or around the tip of Sherman Island likely still experience better survival.

[4] Data were corrected for varying water temperatures at release.

Another factor influencing smolt migration is tidal flow. Tidal influence on smolts probably varies depending on several factors, such as net flow during low flow periods and pumping rates. Changes resulting from tidal flow are generally far greater than changes in net flow. For example in model simulations of a dry month (October 1993), flow rates varied by as much as -125,000 to 110,000 cfs at Jersey Point in one tidal cycle, while net flow varied by much less over the entire month, from about -500 to 5,500 cfs (California Department of Water Resources 1996) (Figure III-8). In model simulations of a wet month (March 1994), flow changes similarly varied between about 110,000 and -125,000 cfs at Jersey Point in one tidal cycle, while net flow varied between about 2,000 and 13,000 cfs for the entire month (Figure III-9). Appendix 3 contains graphs of similar flow simulations for dry and wet conditions at Mallard and Martinez.

Intuitively, it would seem that the small changes in net flow would have a minor influence compared to these large changes in tidal flow. However, we know that flow and hydrodynamic conditions provide migratory cues for smolts (IEP Estuarine Ecology Project Work Team 1996), and net flow could indeed be important. In general, it is probable that modifying flow conditions through pumping operations affects a smolt's ability to detect the crucial pathway to lead them westward to the ocean, although the specific mechanisms affecting their migratory behavior are poorly understand at this time.

CVP and SWP Pumping Plant Operations. Once juvenile winter-run chinook are drawn into waterways of the south Delta by reverse flows, high levels of mortality are likely to result from operation of the gates at the entrance to Clifton Court Forebay, predation during migration across the forebay, and entrainment at the bypass system.

Clifton Court Forebay is an artificially created reservoir used to reduce the effect of tides on SWP project pumping. Typically, the forebay gates are open on ebbing tides and sometimes open on the flood tide. The operation of the Clifton Court Forebay may subject fish in south Delta waterways to inflows of 20,000 cfs with velocities of several feet per second. Operation of the Clifton Court Forebay gates likely causes salmon smolts to become disoriented in the high turbulence during filling, which potentially increases their vulnerability to predation.

The movement of salmon smolts across Clifton Court Forebay to the Skinner Fish Protective Facility is also detrimental due to high levels of predation, primarily by striped bass (see Predation Section later in this Chapter). Numerous studies, in which marked smolts were released into Clifton Court Forebay, have demonstrated that most salmon smolts do not survive to be screened or salvaged (California Department of Fish and Game, unpublished data).

Figure III-8. Estimated flows at Jersey Point for October of water year 1993 from the California Department of Water Resources Delta Simulation Model (Suisun Marsh Version).

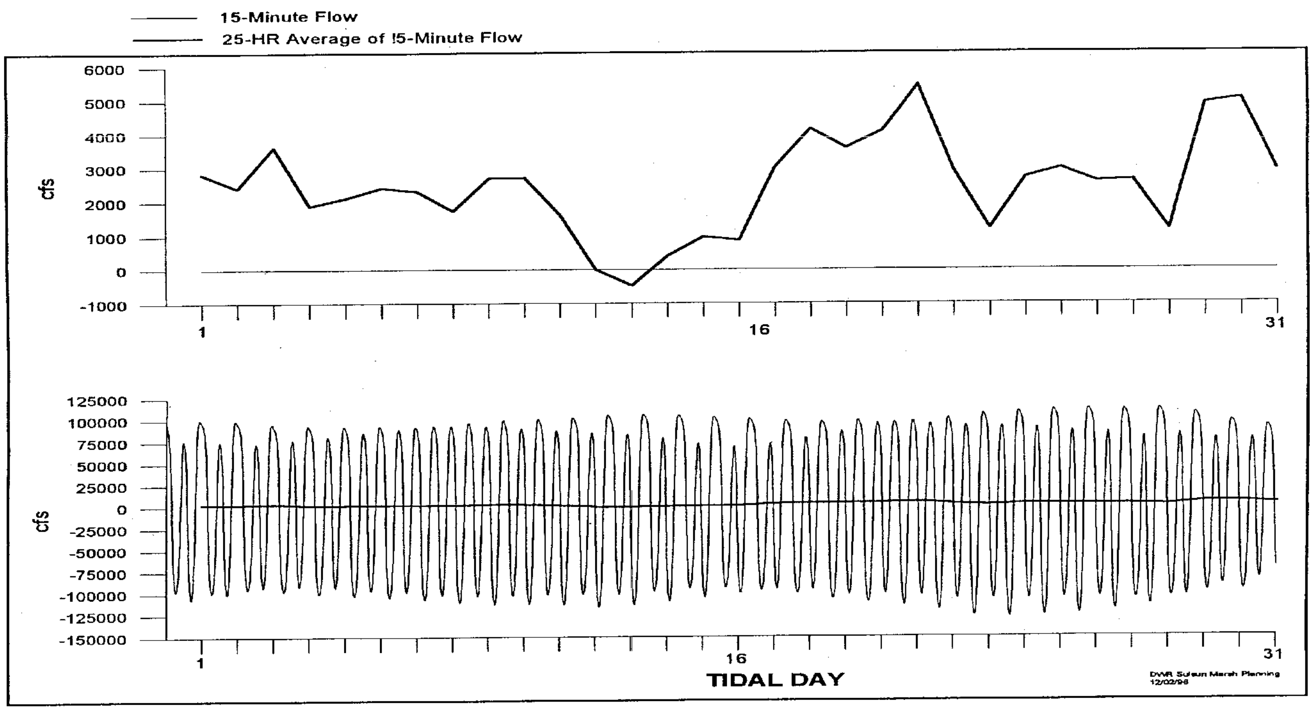
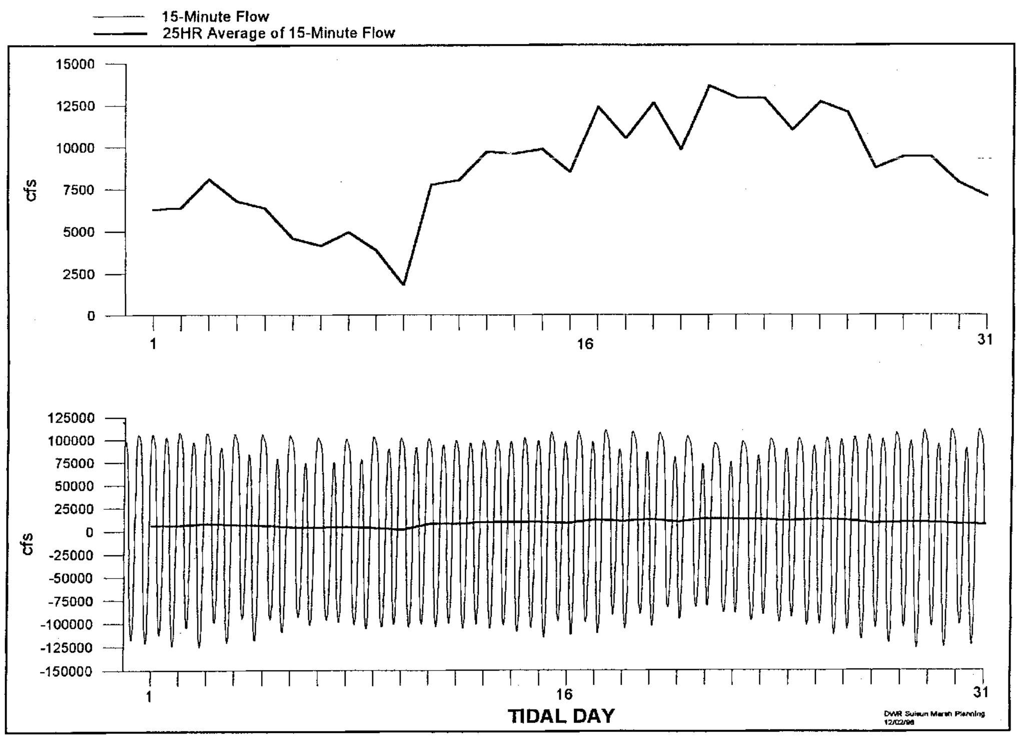


Figure III-9. Estimated flows at Jersey Point for March of water year 1993 from the California Department of Water Resources Delta Simulation Model (Suisun Marsh Version).



In six experimental releases with fall-run chinook, the average prescreening loss rate in release groups through the Forebay was 86%, with a range of 63.3% (at 61°F) to 98.7% (at 74.5°F), (California Department of Fish and Game 1993a). In two experimental releases with late-fall chinook, the mean loss rate was 88.2%, with a range of 77.2% (47.4°F) to 99.2% (54.5°F) (California Department of Fish and Game, unpublished data). Therefore, of the juvenile salmon that enter Clifton Court Forebay, mortalities due to predation may range from 63% to as high as 98%.

Additional mortality occurs once smolts reach the intake screens at either the SWP or CVP plant. Screen efficiencies for chinook salmon smolts at the SWP pumping plant range between 69% and 79% based on equations derived in 1973. It is assumed that screening efficiency and loss is similar at the CVP pumping plant and applicable to winter-run chinook.

Under certain conditions, excessive quantities of detritus and vegetative materials may clog the primary and secondary screen louvers in the fish salvage facility, rendering the facility ineffective in salvaging fish. After prescreening and screening losses occur, additional mortality likely results from the handling and trucking process associated with transporting the salvaged fish to the western Delta for release in areas beyond the influence of the pumps. Although, experiments have shown very little mortality due to the trucking and handling process, it is likely that trucked smolts are vulnerable to high predation soon after their release due to disorientation and the number of predators attracted to the regular release sites (Menchen 1980).

Food Limitation. Recent work has been conducted examining the status and factors affecting food web resources in the Bay-Delta system. Results from these efforts have identified numerous factors which have caused productivity declines in the Bay-Delta, particularly since the commencement of SWP pumping operations. SWP/CVP pumps export on average some 13,000 tons of volatile solids (roughly 3,000-6,000 tons of carbon) from the Delta each year. This loss rate often exceeds carbon lost naturally through the Delta to the Bay. These carbon losses to the pumps exert a negative effect on food supply for primary consumer populations throughout the Delta, but especially in the Central and South Delta areas. In addition, at least half the carbon processed in Suisun Bay originates from the Delta (rather than the Suisun Bay), such that carbon losses via exports are undoubtedly exacerbating food limitation in Suisun Bay, an important migratory corridor for juvenile salmon.

SWP/CVP pumping operations may also be responsible for other related and important inorganic, organic and planktonic losses. The San Joaquin River is an important source of phosphorous, nitrogen and organic carbon. Specifically, the San Joaquin River contains twice as much phosphorous, 3 to 4 times as much nitrogen, and 5 times more fine particulate organic carbon than Sacramento River. Most of the San Joaquin river is currently being diverted from the south Delta by SWP/CVP operations. This loss of nutrients is likely contributing to lowering the overall fertility of the Delta, and thereby, limiting its ability to produce food. Other potential, related effects include an increase in water clarity in some regions of the Delta by exporting sediment, which may reduce plankton production. Also, pumping operations may result in a substantial loss of protista, rotifers, copepods, cladocerans, and other zooplankton, which would reduce their abundance in the Delta and Bay.

Summary of Impacts to Winter-run Chinook from CVP/SWP Pumping Operations. The indirect effects from operating the DCC and pumping plants likely have far greater impacts on the winter-run chinook population than is indicated by the number of fish surviving to the salvage facilities. More likely, the vast majority of juvenile chinook mortality results from the indirect effects of pumping operations, rather than actual entrainment at the pumps. Specifically, juvenile chinook diverted into the central and south Delta experience higher mortality through reversed flows, predation, reduced shallow water habitat for fry, higher water temperatures, possibly small agricultural water diversions, and reduced river inflows during the spring which decreases available nutrients, turbidity, and transport flows for migration. If the DCC gates were not open, fewer juveniles would move into the central and south Delta and in the absence of CVP/SWP, aquatic habitats throughout the central and south Delta would be markedly better for migrating smolts and rearing fry. Finally, the specific mechanisms by which pumping operations influence fish behavior and movement are not well understood. However, salmon arrive in pulses at the pumping facilities indicating that entrainment is not a random process but likely to be directly related to pumping operations.

Influence of a Barrier at the Head of Old River. The barrier at the head of upper Old River was designed to increase the survival of San Joaquin fall-run chinook smolts during their migration through the Delta. However, the barrier may cause additional mortality to those winter-run chinook smolts that enter the central Delta (through the DCC and Georgiana Slough), because the barrier increases the magnitude of reverse flows in the lower Middle and Old rivers.

Studies were designed to evaluate juvenile chinook survival associated with the installation of the barrier at the head of Old River and the increase in reverse flows through middle and lower Old River (California Department of Water Resources 1994). Three sets of paired fall-run chinook CWT groups were released into Georgiana Slough and Ryde in April 1992. Unfortunately, export levels varied at the SWP and CVP pumping plants during these studies, making results more difficult to interpret.

Nevertheless, results for fish released into Georgiana Slough suggest that survival was lowest (survival index of 0.32)[5] with the barrier in operation, during medium export levels. Smolts released into Georgiana Slough with the barrier removed exhibited slightly higher survival

[5] Survival indices are adjusted for different temperatures at release.

(0.41) at higher export rates, as well as higher survival (0.71) at the lowest export rate.

Results from corresponding releases into the Sacramento River at Ryde suggest that barriers may not affect survival of salmon remaining in the main stem river. Survival indices from these releases were lowest at the highest level of export (1.43), mid-range at medium export rates (1.93) and highest at the lowest export rates (2.15). The Ryde results are consistent with previous experiments in which export rates varied, temperatures were constant, and barriers were not a factor.

The differences in survival at the various export levels between the Georgiana Slough and Ryde releases could be due to the Head of Old River barrier. With the barrier in place, the percent of Sacramento River water diverted into middle and lower Old Rivers was found to increase by about 25% to 30% when the barrier is installed (increasing from 44-55% in middle Old River; 32-42% in lower Old River) (Rick Oltman, USGS, pers. comm.). Modeling studies by CDWR determined that little change occurs in the proportion of Sacramento River flow reaching the CVP and SWP pumps with the barrier installed (California Department of Water Resources 1993)[6]. Other modeling studies found that flow patterns and velocities change within the central and southern Delta (California Department of Fish and Game 1993b). CDFG concluded that these changes would increase the risk of chinook salmon fry moving from the central and north Delta waterways into channels in the south Delta (California Department of Fish and Game 1993b). Once in the south Delta where upstream flows further increase, fry would likely be more vulnerable to entrainment at the SWP and CVP export facilities.

In summary, lower survival is difficult to quantify from available information, but data suggest the potential for further adverse impacts to winter-run chinook survival with the operation of the head of Old River barrier. Similarly, additional Delta barriers are likely to further exacerbate this problem. These impacts, however, would likely be minimal if exports were low and San Joaquin flows were adequate.

Existing Protective Measures

Prior to 1992, there were no regulatory measures specifically directed at protecting juvenile winter-run chinook from the effects of SWP and CVP pumping operations in the Delta. In 1992, NMFS issued a one-year Biological Opinion for CVP operations which required several modifications to protect winter-run chinook, including: 1) closure of the DCC gates from February 3 through May 1 to reduce the diversion of juvenile outmigrants into the central Delta, and 2) restricting water diversions in Montezuma Slough from March 1 to April 15 to protect

[6] DWR has conducted tracer studies to track the progress of particles through the Delta using a transport model (California Department of Water Resources 1993).

juveniles from entrainment. Subsequently, NMFS issued the long-term Biological Opinion for CVP operations in 1993, which provided additional protections to juvenile winter-run chinook in the Delta, as follow:

- **Delta Cross Channel Gate Closure.** Gates closed from February 1 through April 30. Intermittent closures from October 1 through January 31, based on the detection of juvenile winter-run chinook in fisheries sampling, or "real-time monitoring".

- **SWP and CVP pumping operations.** No reverse flows in the lower San Joaquin from February 1 through April 30 (QWEST $\geq$ 0), and reverse flows no greater than -2,000 cfs from November 1 through January 31 (QWEST = $\geq$ -2,000).

Also, CDWR and the USBR were authorized to take up to 1% of the winter-run chinook outmigrants annually, at the SWP and CVP pumping facilities. This loss of juvenile winter-run chinook at the pumps is estimated by considering: 1) the number of winter-run chinook sampled at the pumps (using fish length to identify juveniles as winter-run chinook), 2) the proportion of time that fish are sampled, 3) predation rates occurring prior to sampling (75% assumed for CCF, and 15% at CVP facility), 4) screen efficiencies at pumps (75% for both SWP and CVP), and 5) losses occurring during handling, trucking and release (1% mortality).

On December 21, 1994, the USBR reinitiated consultation with NMFS on the CVP/SWP Biological Opinion based on the development of new Bay-Delta standards, under *Principles for Agreement on Bay-Delta Standards*. NMFS, subsequently, amended the CVP Biological Opinion (May 17, 1995) to assess and incorporate these standards, as follow (NMFS 1995a):

- **Delta Cross Channel Gate Closure.** Gates closed from February 1 through May 20. Gates closed for up to 45 days from November 1 through January 31, based on real-time monitoring for the presence of juvenile winter-run chinook.

- **SWP and CVP pumping operations.** A maximum export rate of 65% of inflow from November through January, but subject to adjustment to ensure biological protection. A maximum export rate of 35% of inflow from February through June. Exports during February may be increased to 45% under specified critical water conditions. The previous requirements on reverse flows (QWEST) to limit pumping operations were replaced by the export:inflow ratio parameter.

- **CALFED Operation Coordination group.** This group was established to monitor biological and hydrological conditions throughout the year. This group is responsible for determining whether export rates should be reduced to protect winter-run chinook (and Delta smelt) from November through January. The group will also determine whether exports are increased in February (35%-45%), when water conditions are critically dry in January and the Eight River Index is between 1.0 and 1.5 MAF, to increase water supplies for agricultural and urban water users.

Also, the take allowance of CDWR and USBR was increased to 2%, because of uncertainty related to several parameters used to estimate losses of juvenile winter-run chinook. The main parameter of concern was the length criteria used to identify juvenile winter-run chinook, but the sampling methodology at the salvage facilities also presented uncertainty.

Principles for Agreement on Bay-Delta Standards. The new Bay-Delta Standards, developed in 1994, address outflow standards in the Delta, and other standards that relate to flow, such as salinity and dissolved oxygen. These new standards were developed based on the failure of the State to develop standards protective of fish.

Under the CWA, the EPA is required to review and approve or disapprove water quality objectives established by the states. In 1991, the EPA disapproved the State's proposed Water Quality Control Plan for Salinity for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. Subsequently, the EPA was sued by a coalition of environmental groups to promptly propose Federal replacement standards, as required by the CWA. A settlement agreement followed in which the EPA agreed to propose water quality standards by December 1993, which the agency fulfilled. On December 15, 1994, the EPA presented its draft standards. The proposed standards establish three sets of Federal criteria to protect the beneficial uses of the estuary: (1) salinity criteria to protect the Estuarine Habitat and other designated fish and wildlife uses, (2) salinity criteria to protect the fish spawning designated use in the lower San Joaquin River, and (3) a set of salmon smolt survival index criteria to protect the fish migration and cold fresh-water habitat designates uses in the estuary. Accordingly, the SWRCB then released its final Water Quality Control Plan in May 1995, which EPA approved. The Water Quality Control Plan will be in force for a minimum of three years, at which time it may be revised.

The Water Quality Control Plan includes Delta outflow objectives for the protection of estuarine habitat for anadromous fishes and other estuarine-dependent species. Sacramento and San Joaquin river flow objectives are included to provide attraction and transport flows for the upstream and downstream migrations of various life stages of anadromous fishes. There is also an objective to maintain water quality conditions, which together with other protective measures, will achieve a doubling of natural chinook salmon production, from the average production of 1967-1991. Objectives for Delta Cross Channel closures and export limits, as discussed above, are also included to reduce the diversion of aquatic organisms into the central Delta, and to reduce entrainment at the Delta pumping plants in the south Delta.

The plan also sets other water quality standards, such as salinity objectives for the managed portions of the Suisun Marsh. The plan incorporates objectives from previous plans, which are intended to provide channel water salinities which sustain the vegetative composition of the managed marshlands. However, structural facilities that were built to achieve these objectives, such the Suisun Marsh Salinity Control Structure, may adversely affect winter-run chinook and other listed species. Other proposed activities have the potential to further affect winter-run chinook. Therefore, the salinity standards for Suisun Marsh are to be evaluated by August 1997, including an evaluation based on listed species, and the standards will be modified to minimize adverse impacts on listed fish species.

In addition, the Secretary of the Resources Agency, the Secretary of the California Environmental Protection Agency, the Secretary of the Interior, the Secretary of Commerce, the Administrator of the Environmental Protection Agency, and a variety of interested parties signed the "Principles for Agreement on Bay-Delta Standards Between the State of California and the Federal Government." The agreement was signed to provide ecosystem protection for the Bay-Delta Estuary, and the signatories agreed to its implementation through the State Water Resources Control Board.

CALFED Bay-Delta Program

CALFED has also been charged with developing a long-term comprehensive plan to restore ecological health and improve water management for beneficial uses of the Bay-Delta. CALFED is a consortium of state and federal agencies with management and regulatory responsibilities in the Bay-Delta. These agencies include: Department of Water Resources; Department of Fish and Game; California Environmental Protection Agency including the State Water Resources Control Board; Bureau of Reclamation; Fish and Wildlife Service; U.S. Environmental Protection Agency; National Marine Fisheries Service; and the Army Corps of Engineers as a cooperating agency.

The CALFED program will address four main categories of Bay-Delta problems: (1) ecosystem quality; (2) water quality; (3) water supply reliability; and (4) system vulnerability. The process outlined by CALFED is to propose alternative solutions, followed by a broad-based environmental review to choose the preferred alternative, and finally, implementing the preferred alternative in stages. At the time of this writing, three alternatives have been proposed and include:

Existing system conveyance where little or no modifications are made to the flow capacity of the existing Delta channels.
Through Delta conveyance where a variety of modifications to Delta channels would be made to increase the conveyance efficiency.
Dual Delta conveyance using a combination of improved through Delta conveyance and

conveyance isolated from Delta channels.

CALFED has developed some guiding assumptions for their program. One important assumption is that their ecosystem restoration program will improve ecosystem functions and promote the recovery of listed and candidate species. The alternatives being proposed all include physical habitat restoration as well as improved management of flows. Such flow management aims to reduce the impacts of diversions on the environment during critical periods, and to enhance flows during periods which would produce the greatest benefits to ecosystem health. The intent of this approach is to allow ecosystem restoration, while placing fewer constraints on the operation of water supply systems. Where competition for Bay-Delta resources makes it impossible to avoid impacts to species, habitats, or ecological functions, CALFED proposes to compensate by reducing other sources of mortality or improving habitats elsewhere in the Bay-Delta.

Various habitat improvements that are currently being considered include: (1) restoring and preserving shallow water tidal habitat and riparian habitat; (2) converting diked bay lands to tidal wetlands; and (3) improving riverine habitat by setting back levees and creating meander belts. CALFED is also evaluating the potential to purchase or develop water from willing sellers in order to increase instream flow, increase outflow from the Delta to the Bay, or to be used for other environmentally beneficial measures. Other measures under consideration are: (1) controlling exotic species introductions; (2) installing fish screens; and (3) protecting and managing fish populations, through real-time monitoring of their location and health, such that water system operations can be modified to benefit fish.

Physical Habitat Alteration

A vital, functioning Sacramento River and Bay-Delta ecosystem includes not only the hydrologic components, but the closely interrelated riparian habitats, instream gravel resources, and tidal marsh habitats. Winter-run chinook, like all species and runs of salmon, are dependent upon these habitats to reproduce and survive successfully. However, the majority of the riparian and marsh habitats in the Central Valley have been eliminated over the course of the past 100 years, and natural sources of spawning gravel have been greatly reduced.

Loss of Riparian Habitat from Levee Building and Bank Protection

Profound alterations to the riverine habitat of the Central Valley began with the discovery of gold in the middle of the last century. Dam construction, water diversion, and hydraulic mining followed launching the Central Valley into the era of water manipulation and coincident habitat degradation.

Hydraulic mining led to frequent flooding in the later 19th Century, prompting the construction of levees. However, severe flooding prevailed, which prompted the USACOE to develop plans for a more extensive levee system. Congress authorized the Flood Control Act of 1917, which initiated the Sacramento River Flood Control Project. The project covered a distance of about 184 river miles mainly between Ord Bend and Collinsville, and included not only a comprehensive levee system, but overflow weirs, drainage pumping plants, and flood bypass channels. The project was intended to provide protection from floods, improve access for riverboat commerce, and to scour and remove sediment deposits caused by hydraulic gold mining.

The levees, however, began to deteriorate after the completion of Shasta Dam in 1941. Following disastrous flooding and extensive erosion damage to the project in the 1950s, the USACOE requested Congress to authorize a long-range program of bank protection and setback levees. The Flood Control Act of 1960 was passed authorizing the Sacramento River Bank Protection Project to provide protection for the existing levees constructed under the Flood Control Project (U.S. Fish and Wildlife Service 1987b).

At present, the Flood Control Project consists of about 1,300 miles of levees, overflow weirs, pumping plants, and bypass channels on the Sacramento River and adjacent sloughs and streams from RM 0 at Collinsville to RM 194 near Chico (U.S. Army Corps of Engineers 1993b). Phase I of the Bank Protection Project is complete and resulted in about 430,000 linear feet of bank protection work. About 319,000 linear feet of Phase II has been completed, and 86,000 linear feet of Phase II remains to be constructed, including the Contract 42A project between RM 78 (near the confluence of the Feather River) and RM 144 (at Colusa) (U.S. Fish and Wildlife Service 1993b).

Impacts on Riparian Habitat. About 150 years ago, the Sacramento River was bordered by up to 500,000 acres of riparian forest, with bands of vegetation spreading 4 to 5 miles (Resources Agency 1989). By 1979, riparian habitat along the Sacramento River diminished to 11,000-12,000 acres or about 2% of historic levels (McGill 1979). More recently, about 16,000 acres of riparian vegetation has been reported (McGill 1987). The degradation and fragmentation of riparian habitat has resulted mainly due to the flood control and bank protection projects, together with the conversion of riparian land to agriculture (Jones and Stokes Associates 1993b).

The size and location of the Flood Control Project levees were designed on technical considerations and land use restrictions. Upstream of Colusa (RM 144), levees were set back from the channel to allow for the collection of floodwater, management of eroded material, and stream channel meandering. Conversely, the levees downstream between Colusa and Verona were constructed close together to increase channel flow and to maintain the necessary hydraulics for the flood control weirs (U.S. Army Corps of Engineers 1993). The levees further downstream on the lower Sacramento River were also built very closely together to concentrate and accelerate streamflow to maximize the sediment carrying capacity of the water.

The strategy of encouraging the river's erosive forces resulted in abrading the important berm areas between the river and levees below Colusa. These berms supported riparian vegetation which grew next to and shaded the near shore water surface. This overhanging vegetation is referred to as shaded riverine aquatic (SRA) habitat (U.S. Fish and Wildlife Service 1993c).

Bank protection work further reduced SRA habitat. Bank protection entails lining the irregularly shaped river banks with fairly uniform quarry rock (i.e. rip-rap) which halts erosion and reduces substrate diversity. Project work also involves removing vegetation along the bank and upper levees, which strips most instream and overhead cover in the nearshore areas. Additionally, nearshore aquatic areas are deepened and sloped to a uniform gradient, such that variable water depths, velocities, and direction of flow are replaced by consistent, moderate to high velocities.

Small scale bank protection projects also cause important losses of SRA habitat. Eddies form on the downstream and upstream ends of small rock revetment projects, which causes scouring behind stone revetment and erosion. This leads to more bank stabilization work and the associated loss of SRA habitat.

Maintenance of bank protection continues to suppress SRA habitat. Some reclamation and levee districts maintain strict practices of suppressing all woody growth on levees, berms, and banks. Others suppress woody growth only on levees and banks. Vegetation is sometimes allowed to grow to a certain stage and is then removed. In some areas, no maintenance is conducted, and riparian vegetation establishes itself to the extent that the underlying rip-rapped bank is no longer visible.

A further impact of the flood control project and bank protection work has been suppressing the successional development of the Sacramento River riparian forest. A meandering channel and natural flow regime is needed for willows and cottonwoods to become successfully established. As mature trees age and eventually die, they need to be replaced by successional vegetative stages beginning with the establishment of willows and grasses along the outside, or depositional, bends in the river. These first plants trap sediment to form the beginning point bars which eventually become terraces where species less tolerant of flooding become established. This area will eventually evolve into a riparian gallery forest (State Lands Commission 1993). This regeneration cycle of the riparian forest, from initial willow seedling establishment through climax forest and back to seedlings, is about 80-100 years. This cycle is directly related to the movement, or meandering, of the river. If the meander cycle is not allowed to repeat, then riparian forest successional development will not occur. Accordingly, levee construction and bank protection projects have prevented the lower river from meandering and inhibited the renewal of the riparian forest (State Lands Commission 1993).

In addition, alteration of the river's natural flow regime has impaired the regeneration of riparian vegetation. Historically, the seasonal flow patterns included high flood flows in the winter and spring with declining flows throughout the summer and early fall. As flows declined during the summer, the seeds from willows and cottonwood trees, deposited on the recently created sand bars, would germinate, sprout, and grow. The roots of these plants would follow the slowly receding water table allowing the plants to become firmly established before the next rainy season.

Following construction of Shasta Dam, the flow regime of the river was essentially reversed. Releases to the river from the dam became reduced in the fall and winter to fill the reservoir, and then either held steady or increased through the spring and summer to meet irrigation demands. Riparian seedlings annually established at the waters edge in the spring and summer are now destroyed by inundation during the irrigation season and thereby fail to contribute to the regeneration of riparian habitat.

Finally, operation of the Flood Control Project, mainly south of Chico, also precludes the reestablishment of a dynamic riparian ecosystem by altering the flow regime. The Flood Control Project directs floodflows away from the leveed main channel, leaving only small remnants of riparian habitat south of Colusa.

Effects on Winter-run Chinook. Large areas lacking riparian vegetation with SRA habitat may limit the viability of the Sacramento River to support anadromous fish (Jones and Stokes 1993b). Studies have shown high preference of juvenile salmon for these natural shoreline areas, indicating that further loss of SRA habitat could hinder the successful rearing of juvenile winter-run chinook (U.S. Fish and Wildlife Service 1993b). Cumulative impacts to winter-run chinook from levee construction and bank protection include loss of instream and above-water cover, elimination of slow and slack water velocities, reduction in food availability, and potentially, the raising of water temperatures to levels detrimental to juvenile salmonids.

Woody debris and overhanging vegetation within SRA habitat may also provide important escape cover for salmon fry from predators. Cut banks, regardless of the presence of overhanging vegetation, may be preferred by salmon fry. Three times as many salmon and steelhead fry are found near cut banks than in artificial rock revetment sites (California Department of Fish and Game 1982). Also, fish species composition at rock revetment sites is not characteristic of salmon and steelhead habitat, but rather indicates a potential for greater predation on juvenile salmonids and competition for food.

Many aquatic and terrestrial insects, which provide an important component in the juvenile salmon diet, are dependent upon riparian habitat. Aquatic invertebrates thrive on the organic material produced by healthy riparian habitat, while terrestrial invertebrates (such as aphids) depend upon this habitat for summer resting sites, and for breeding and metamorphosing. These invertebrates drift from the natural riparian bank areas and side channels into the river, where juvenile chinook salmon feed. Studies of stomach contents of 466 juvenile salmon from the Sacramento River at RBDD, Vina, and Chico Landing, showed that during a portion of the year, a significant portion of the diet was composed of aphids (California Department of Fish and Game 1982). In fact, juvenile chinook preferentially selected terrestrial insects, compared to other food available. Without the presence of nearshore riparian vegetation to serve as insect habitat, such terrestrial invertebrates are not as available to salmon as a food source for salmon (California Department of Fish and Game 1985).

In addition, recent research has provided evidence that spring to early summer water temperatures in the lower Sacramento River may have risen from 4°F to 7°F since the late 1970s (Mitchell 1987, Reuter and Mitchell 1987). Reuter and Mitchell (1987) indicated that factors other than flow are responsible for these warmer temperatures, although definitive factors were not identified. Potentially, the large cumulative losses of shade along the river may in part influence water temperatures in this reach. The shaded habitat created along the banks by SRA cover is considered critically important in the lower river, where water temperatures are difficult to control via reservoir releases.

Existing Protective and Mitigation Measures. Until 1989, mitigation measures for bank protection projects have provided little compensation for loss of anadromous fish habitat (U.S. Fish and Wildlife Service 1993c). Prior to this, mitigation was either non-existent or, since 1976, focused on compensating for terrestrial resources.

Since 1989, and in response to Contract 42A, mitigation replanting has become an essential part of compensation efforts. However, most plantings have not been successful in providing shade replacement because they occurred either on high berms with rock revetment extending into the river, or were established on the landward side of the levee. At best, replanting of riparian species replaces only a segment of the original value of river-edge riparian habitat. The irregular banks, with root wads, crevices, and instream vegetation are lost, and it is improbable that these habitats are ever recreated (U.S. Fish and Wildlife Service 1993c).

In a 1991 biological opinion on winter-run chinook, NMFS analyzed various mitigation options for Contract 42A and rated them in the following order of preference: 1) low bank revetment, 2) tree tethering on rock revetment, 3) dredge berms, 4) gravel-covered revetment, 5) rock revetment with fish groins, and 6) hard points (National Marine Fisheries Service 1991a). These recommendations were incorporated into Contract 42A plans, but further analysis by the USFWS found these measures were inadequate to compensate for impacts to SRA habitat.

Currently, the USFWS policy on SRA habitat in the Sacramento River is for "no net loss of existing habitat value" (Resource Category I) because of its scarcity and unique value to fish and wildlife species and its irreplaceability under existing construction and maintenance strategies by the USACOE (U.S. Fish and Wildlife Service 1992b).

Following this, the USACOE reinitiated consultation on contract 42A at NMFS's request. During the consultation, NMFS clarified its mitigation requirement for "adequate" mitigation. Due to the cumulative loss of SRA cover already incurred, NMFS concluded that all losses of existing habitat caused by contract 42A and other bank protection projects must be fully mitigated in order to avoid jeopardy under the ESA. The USACOE is currently constructing mitigation for contract 42A, but it remains to be determined whether it will provide full compensation for impacts to existing SRA habitat.

In a letter to NMFS, the USACOE expressed its intent to reevaluate the Sacramento River Bank Protection Project to investigate alternative erosion control and management methods, including setback levees and opportunities for environmental restoration (U.S. Army Corps of Engineers 1996). This study will incorporate objectives of the 1994 Upper Sacramento River Fish and Wildlife Habitat Restoration Study to identify opportunities for restoring fish and wildlife habitat within the context of the bank protection project. The USACOE's intention is to restore habitat associated with bank protection to provide habitat values above the amount needed to achieve mitigation. Potential restoration measures include oxbow restoration, riparian revegetation, setback levees, levee maintenance, and side channel development. The USACOE's study will evaluate restoring specific sites (nodes) as well as linking sites (corridors) in conjunction with evaluating erosion protection measures. Implementation of these restoration measures will depend on congressional authorization of the Sacramento River Bank Protection Project and Flood Control Project to include protection of riparian habitat values for fish and wildlife. Implementation will also depend on a non-Federal sponsor to cost share design and construction costs, and to operate and maintain the project following completion.

New environmental direction was given to the USACOE with passage of the Water Resource Development Acts (WRDA) of 1986, 1988, 1990 and 1992, which gave the USACOE an environmental mission co-equal with its traditional missions of flood control and navigation. Thus, the USACOE is currently able to act pro-actively in protecting and restoring riparian habitat. An example of a riparian restoration project under section 1135 of WRDA is the Murphy Slough restoration project where the USACOE is authorized to modify flood control and bank protection projects for the purpose of improving the environment.

Instream Gravel Resources

The construction of Shasta and Keswick dams eliminated the major source of gravel recruitment to the Sacramento River, leaving only tributaries and the flood plain to supply gravel. Clear Creek has made substantial contributions to the gravel supply in the recent past, but the construction of Whiskeytown Dam and over four decades of mining has virtually eliminated this source as well. Cottonwood Creek has since been the source of 85% of the gravel entering the river between Redding and Red Bluff. Yet, a large mine is in operation on the creek and five others are being considered. These threaten to remove over 30 million cubic yards of gravel from the creek in the next 30 years (Resources Agency 1989).

Gravel sources from banks and the floodplain directly along the Sacramento River have also been substantially reduced by levee and bank protection projects and mining. Levee and bank protection projects restrict the natural meandering of the river, which normally would release gravel into the river through erosion and deposition processes. Aggregate mining along the Sacramento River has reduced gravel supplies mainly from past operations in the Redding area but also from activities near the confluence of Clear Creek (Resources Agency 1989), and Stoney and Thomes creeks.

In addition, reductions in gravel from dam construction, gravel mining, and bank protection has led to an imbalance in the dynamics of the river system. In a healthy, functioning riverine ecosystem, energy produced by river flow is dissipated by the transport of gravel and sand through the water column. When these sources of work are eliminated, the river's energy is instead dissipated by scouring the remaining gravel in the streambed and eroding the river's bed and banks (State Lands Commission 1993).

Effects on Winter-run Chinook. Suitable gravel resources in the river channel are required for salmon reproduction and rearing. Winter-run chinook depend on suitable habitat existing in the river on the valley floor, as they are now prevented from ascending to their historic spawning areas in the headwaters of the Sacramento River. The amount of spawning gravel substrate presently available for winter-run chinook has not been empirically estimated. However, it is generally thought that available spawning substrate is sufficient to support the winter-run chinook population at its present low level. As the population recovers, spawning gravel availability in the upper Sacramento River could potentially become limiting, but definitive studies are needed. Perhaps the more important problem is that deficiency in gravel substrate can lead to erosion of the river's streambed and streambanks, which could further reduce available spawning and rearing habitat.

Mitigation Measures. To date, efforts to restore spawning gravel in the upper Sacramento River appear helpful. In 1990, CDWR placed 100,000 cubic yards of spawning gravel in the Upper Sacramento River between Salt Creek and Clear Creek to restore the degraded spawning riffles used by winter-run chinook, as part of CDWR’s mitigation for the direct impacts of its Delta pumping facility. Recent monitoring of these gravel restoration sites have indicated that the new gravel became suitably redistributed during high flows. The deposited gravel appears to provide an additional benefit of filling in certain depression areas on point bars where juveniles have been susceptible to stranding (H. Rectenwald, pers. comm.). In October 1995, an additional 7,000 tons (approximately 4,300 cubic yards) of clean and graded gravel was stockpiled on the streambank near Keswick. This gravel was naturally distributed during high flows in January 1996, thus emulating natural erosive and depositional processes (P. Warner, pers. comm.).

Loss of Tidal Marsh Habitat

Historically, tidal marsh was one of the most widespread habitat types in the Sacramento-San Joaquin Delta and San Francisco Bay. At present, only 2% of marsh habitat remains in the Delta, and about 15% remains in the San Francisco Bay area (including San Francisco, San Pablo and Suisun bays) (San Francisco Estuary Project 1992, Dedrick 1989). In the Delta, tidal marsh habitat is now restricted to remnant patches principally in channels where the area between levees is wide enough or where substrates are deposited high enough for tules and reeds to survive (State Lands Commission 1991). In the Bay, remaining tidal marshes are located in isolated pockets or in linear strips along sloughs or bay-front dikes (Josselyn 1983). The largest contiguous marshes lie in Suisun Bay and along the Petaluma River. A complex mosaic of salt and brackish marshes is also located along the Sonoma and Napa river systems and along the northern shore of San Pablo Bay.

Loss of marsh habitat has resulted primarily from the conversion of wetlands for farming, salt production, and more recently, urbanization. Based on proposals for highways, airports, and residential housing and on the long-term general plans of local governments, substantial future wetland degradation and alteration is expected to occur in the estuarine basin.

Effects on Winter-run Chinook. Few empirical studies of the use and importance of marsh habitat to juvenile chinook salmon have been conducted in the Sacramento-San Joaquin Delta and San Francisco Bay-Estuary. However, some recent monitoring in the Delta and Bay verify that juvenile chinook salmon use tidal marsh habitat. Salmon in the winter-run chinook size range were sampled in tidal marsh areas of Liberty Island and Little Holland Tract (California Department of Water Resources memorandum 1996). Also, juvenile fall-run chinook salmon were sampled in a recently restored tidal marsh area at the Sonoma Bay Wetland Demonstration Project along San Pablo Bay (CH2M Hill 1996). Research in the Pacific Northwest has found that tidal marsh habitat is important to juvenile salmonids (Levy and Northcote 1982, Healey 1982, Meyer 1979, Levy et al. 1979, Levy and Northcote 1981, MacDonald et al. 1987, Dorcey et al. 1978). It is expected that the importance of marsh habitat to juvenile chinook in this estuary corresponds to that found in the Pacific Northwest.

Of all the salmonid species, juvenile chinook salmon show the strongest tendency to utilize marsh habitat (Levy et al. 1979, Healey 1982). The benefits of tidal marshes to juvenile chinook salmon include: 1) the contribution of nutrients to the detritus-based food chain, 2) the availability of rich feeding habitat, 3) refugia from predators, and 4) the provision of suitable habitat for the physiological adaptation of juveniles to seawater. Chinook populations in river systems having well-developed estuaries with marshes may in fact have higher productivity due to the additional rearing areas than in systems without such habitat (Levy and Northcote 1982).

The dependence of winter-run chinook on tidal marsh habitat in the Sacramento-San Joaquin Delta likely depends on the water year type. Tidal marsh and slough habitat may be more important to winter-run chinook in wetter years or in wet events in dry years. Under these conditions, fry may be flushed into the estuaries with early winter storms (F. Fisher, pers. comm.), and utilize tidal marsh habitat.

Tidal marshes are extremely productive, compared to other kinds of vegetation, with each acre growing as much as twelve tons of dry plant matter each year (Atwater et al. 1979). Tidal marshes contribute to the overall productivity of intertidal and subtidal habitats by releasing detritus which is consumed by benthic grazers, such as chironomids. Juvenile chinook salmon, in turn, select chironomids as a prey source in tidal marsh channels (Northcote et al. 1979, Levy et al. 1979, Levy and Northcote 1981, Schreffler et al. 1992). This detritus-based food chain (detritus-chironomids-juvenile chinook salmon) has been described for estuarine wetlands, particularly for chinook fry (Northcote et al. 1979, Schreffler et al. 1992). It follows that an extreme loss of this habitat, as has occurred in the Delta and estuary, would affect the productivity and food availability in estuarine areas.

Tidal marshes and sloughs are most heavily used by chinook fry, whereas smolts tend to inhabit deeper waters away from shore (Healey 1991). Chinook fry move into the edges of marshes on high tides into the highest points reached by the tide, and then retreat into tidal channels and creeks that dissect the marsh areas as the tide recedes. Chinook fry prefer tidal channels with low bank elevations typical of youthful marshlands, and tidal channels with many subtidal refugia (Levy and Northcote 1981).

Mitigation Measures. Under Section 404 of the CWA, the federal government administers the most comprehensive wetlands regulatory program within the Delta and Estuary. Federal agencies with primary roles include the USACOE, the Natural Resource Conservation Service, EPA, USFWS, and NMFS. Through authority of the Fish and Wildlife Coordination Act, these federal trustee agencies review and comment on all projects that may affect wetlands. The USFWS also pursues non-regulatory habitat acquisition in the Delta and estuary through several programs, including the National Wildlife Refuge System. In addition, the Water Resources Development Act of 1992 under section 204 authorized the USACOE to implement projects for the protection, restoration, and creation of aquatic and ecologically related habitats, including wetlands, in connection with dredging for construction, operation, or maintenance of an authorized navigation project.

State agencies with regulatory responsibility that affect wetlands include the SWRCB, Regional Water Quality Control Boards, and the San Francisco Bay Conservation and Development Commission (SFBCDC). The SFBCDC is charged with preventing unnecessary filling of the Bay and protecting Suisun Marsh. The California Coastal Conservancy is a non-regulatory state agency that oversees an active program of wetland acquisition, restoration and enhancement. Non-profit entities, such as the local chapters of the Audubon Society and the Nature Conservancy, also undertake projects to protect and preserve wetlands. In addition, the CALFED Bay/Delta Program, which is a joint effort among state and federal agencies with management and regulatory responsibilities in the Delta, is evaluating alternatives to solve problems in the Bay/Delta estuary. Creation of shallow water habitat is thus far included as an important goal of the CALFED program.

Despite these federal, state and private efforts, implementation of wetlands protection and restoration has proven inadequate to preserve valuable wetland resources. A higher level of protection exists under the present regulatory framework as compared to twenty years ago, but this regulatory protection remains inadequate as wetland resources have continued to decline.

Additionally, there has been a program developed to identify a vision of what is needed to provide a healthy wetlands ecosystem in the San Francisco Bay Area. This program, called the Regional Wetlands Ecosystem Goals Project, will use available scientific knowledge to identify the types, amounts, and distribution of wetlands and related habitats needed to sustain diverse and healthy communities of fish and wildlife (Regional Wetlands Goals Project 1995) . This project will provide a biological basis to guide a regional wetlands planning process for public and private interests seeking to preserve, enhance, and restore the ecological integrity of wetland communities. The concept of developing wetland goals was recommended by the Governor’s Wetlands Policy and by the Comprehensive Conservation and management Plan of the EPA’s San Francisco Estuary Project.

The regional wetland goals should be particularly useful to the CALFED Bay-Delta Program as well as Category 3 projects in the SWRCB’s 1995 Water Quality Control Plan for the estuary, CDFG, the San Francisco Bay Conservation and Development Commission, San Francisco Bay Joint Venture, San Francisco Bay Regional Water Quality Control Board, USACOE’s Long Term Strategy for Dredged Material, USFWS and NMFS.

Water Pollution

Water quality problems in the Sacramento River and Bay-Delta stem from point-source and non-point sources of pollution, and pose a variety of threats to winter-run chinook. Particular areas of concern for point-source pollution include heavy metal contamination from Iron Mountain Mine; selenium discharge; and contamination from various municipal and industrial discharges. Potential problems from non-point sources of pollution include high levels of suspended sediments and contaminants from stormwater discharge; and elevated levels of nutrients, herbicides and pesticides from agricultural drainage.

Point Sources of Pollution

Iron Mountain Mine

The largest discharge of toxic material affecting the Sacramento River area is Iron Mountain Mine (IMM), which is an inactive copper-zinc and pyrite mine located in the Spring Creek watershed near Keswick Dam. The unique characteristics of the mine, together with the natural occurrence of nearly pure sulfide deposits, create conditions that are nearly optimal for the production of acid mine waters. Inside the abandoned workings in the mountain, an uncontrolled sulfuric acid reaction continuously occurs fed by water and oxygen that reaches the pyrite though tunnel openings and mine shafts. The acid mine drainage is among the most acidic and metal laden anywhere in the world (U.S. Geological Survey 1990). The next largest acid mine discharge in the State contains less than 10% of the metal load of the IMM discharge. The IMM discharge is at least equal to all the industrial and municipal discharges of metal into the San Francisco Bay and Delta Estuary System (U.S. Environmental Protection Agency 1992).

Effects on Winter-run Chinook. There are three metals of primary concern: copper, zinc, and cadmium. The early life stages of salmon are the most sensitive to these metals, based on laboratory and on-site toxicity studies (Finlayson and Wilson 1989). Discharge of the complex mixture of numerous toxic metals into the Sacramento River has caused massive kills of resident and anadromous fish, exposed fish to chronic toxicity, degraded water quality, and contaminated fish tissue and fish habitat (Table III-5). Metal concentrations on occasion have been acutely toxic to salmon, and these concentrations frequently exceed chronic toxic levels (U.S. Fish and Wildlife Service 1987c).

Through history, the impacts on winter-run chinook have varied, as conditions under which metals have been released into the Sacramento River have differed. Prior to the construction of Shasta Dam, the peak metal loads generated during major storm runoff were naturally synchronized with increased runoff from the unimpaired flows of the Sacramento River, and the toxics were likely diluted. Also, winter-run chinook spawned safely above the point of discharge, in the headwaters of the Sacramento River, such that the most sensitive life stages were likely protected from the waste discharges.

When Shasta Dam began operating in 1943, it confined the spawning and rearing of winter-run chinook to the river below the discharge. Shasta Dam also stored a portion of the natural flow of the Sacramento River in Shasta Lake, reducing flows available to dilute toxic discharges. When Keswick Dam was built in 1950, the sediment load from Spring Creek, which previously was flushed downstream, caused a delta to form in the Spring Creek arm of Keswick Reservoir. Over time, this chemical process has created an enormous deposit of contaminated sediments in excess of 111,000 m^3 (U.S. Geological Survey 1993).

Subsequently, in 1963, the USBR constructed a small dam on Spring Creek to control this sediment loading and to prevent the choking of the Spring Creek powerplant, built the following year. The Spring Creek powerhouse generates hydroelectric power from Whiskeytown Reservoir releases, which are diverted via a penstock system, to Spring Creek just below the small dam. Under certain atypical operations of the Spring Creek powerhouse and the Keswick Reservoir, the sediment deposit in the reservoir can be mobilized and enter the river (Central Valley Regional Water Quality Control Board 1988). These operations are most likely to occur in the summer due to power peaking operations and under drought conditions, potentially affecting sensitive life stages of winter-run chinook.

A secondary use of the Spring Creek dam is to allow for storage and controlled release of contaminated water from the Spring Creek basin. Waste is metered out on a year-around basis to abate the quantity of contaminated water in the reservoir while achieving the best water quality possible, unless spillages occur. During the summer, the dam releases up to 5,800 acre-feet of stored waste to the river, potentially affecting winter-run chinook spawning and incubation. In the winter, some major storm events may exceed the storage capacity of the Spring Creek Dam, resulting in uncontrolled spills of contaminated water. Metal loadings from these spills, on some occasions, have been inadvertently diluted by Shasta Dam releases, which were made to reserve flood space in the reservoir. On other occasions, releases from Shasta Dam have not been made resulting in high metal concentrations. The USBR does not have Congressional authorization to provide dilution flows to ameliorate contaminated discharges from Spring Creek, but when possible, does accommodate dilution releases within its annual operations.

In addition, operation of the Spring Creek powerhouse has changed the dynamics of how the river is dosed with metals. Metal concentrations in the river exhibit wide daily fluctuations when the powerhouse is not operated at a consistent flow-rate, such as occurs during power peaking operations (Central Valley Regional Water Quality Control Board 1988, Finlayson and Wilson 1989).

Table III-5. Chinook Salmon and Steelhead Trout Mortality Episodes in the Sacramento River Attributed to Trace Metal Contamination from the Iron Mountain Mine Site Based on Actual Observations and Bioassay-based Calculations (U.S. Fish and Wildlife Service 1959, Nordstrom 1985, CDFG 1978, Finlayson and Wilson 1979, U.S. Environmental Protection Agency 1986, Curtis 1989).

Date	Observation Location	Adult	Juveniles	Estimated Number of Mortalities
1940	Below Shasta Dam	X		Unknown*
Nov 1944	Balls Ferry		X	30% of spawning run*
Winter 1945	Balls Ferry		X	Unknown*
1948	Below Shasta Dam			Unknown*
Apr 1949	Ball Ferry		X	Unknown*
Apr 1955	Redding		X	100,000*
Nov 1955	Keswick Dam	X	X	42*
Feb 1956	Redding	X		Unknown*
Jan 1957	Redding	X		Unknown*
Feb 1957	Redding	X		Unknown*
Feb 1957	Redding	X		25*
Feb 1957	Redding		X	250*
Sept 1957	Redding		X	50,000*
Jan 1959	Keswick Dam	X		422*
Jan 1959	Redding		X	Unknown*
Apr 1959	Redding	X		25*
Dec 1960	Redding			Unknown*
Feb 1961	Redding	X		50*
Feb 1962	Redding	X		98*
1963	Unknown	X	X	>100,000*
Feb 1964	Redding			100,000*
Feb 1966	Redding	X		136 steelhead trout*
Apr 1966	Redding	X		130 steelhead trout*
Jan 1967	Redding	X		785 steelhead trout*
1969	Unknown	X	X	>100,000*
Jan 1978	Redding		X	37% of fry†
Mar 1979	Keswick Dam		X	4 events @ 10% of fry‡
Mar 1979	Keswick Dam		X	1 event @ 50% of fry‡
Feb 1980	Keswick Dam		X	1 event @ 25% of fry‡
Feb-Mar 1981	Keswick Dam		X	13 events @10-20% of fry‡
Nov 1981	Keswick Dam		X	4 events @ 10% of fry‡
Mar 1983	Keswick Dam		X	3 events @ 10% of fry‡
Apr 1983	Keswick Dam		X	1 event @ 10% of fry‡
May 1983	Keswick Dam		X	1 event @ 10% of fry‡
Jun 1983	Keswick Dam		X	1 event @ 10% of fry‡
Feb 1986	Keswick Dam		X	5 events @ 10% of fry‡
Apr 1986	Keswick Dam		X	1 event @ 10% of fry‡
Jun 1986	Keswick Dam		X	Unknown‡

*Actual observations.
‡Mortality estimates reported by Rectenwald (1989) for Spring Creek spill episodes only for events when water quality was constantly monitored. Mortality calculations were based on adjustments of reported total metals concentrations to dissolved values and comparisons of exposures to bioassay results in Finlayson and Verrue (1982).
†Based on an in situ bioassay of eggs and fry.

The extent of the river reach affected by IMM discharge has not been thoroughly defined. It depends on a number of variables, which include: 1) dissolved metal concentration, 2) duration of exposure, 3) dilution of the toxic plume as clean accretions enter the river downstream of Keswick Dam, and 4) the effects of toxic sediments released into the river.

Existing Protective Measures. The SWRCB has set Basin Plan objectives for heavy metals in the upper Sacramento River, which are protective of the early life stages of salmon. These objectives include 5.6 parts per billion (ppb) for copper, 16 ppb for zinc, and 0.22 ppb for cadmium. However, these concentrations of toxic metals are usually exceeded in the Sacramento River below Keswick, particularly during winter storm events.

Application of the CWA to IMM in 1977 initiated several pollution control efforts to help meet these standards. However, the responsible party at the mine largely lacked the resources to apply "best available technology" for removal of metals from collectable discharges. Nevertheless, several enforcement actions were taken during the 1970s and 1980s.

In 1980, a Memorandum of Understanding for Spring Creek Debris Dam was signed by the USBR, SWRCB and CDFG. This agreement implemented actions to protect Sacramento River from heavy metal loading in Spring Creek. Specifically, the monitoring and operations of the Spring Creek Reservoir, Shasta Dam and Whiskeytown Reservoir were improved over the previous arrangements.

In 1983 the IMM site was listed on the EPA National Priorities List of the nations most contaminated sites (Superfund sites). During the drought of 1989 through 1993, the EPA ordered installation and operation of emergency chemical treatment plants during the wet season, which were capable of treating only a portion of the most concentrated IMM discharges. These plants applied the best available technology capable of removing 99% of the metal and acid for the treated flows. Yet, it was still not possible to attain Basin Plan objectives due to limitations in the capacity of the emergency treatment plant, large contaminated discharges associated with surface runoff from area sources, and a limited supply of water in Shasta Reservoir during the recent drought. Uncontrolled releases of waste occurred from Spring Creek Reservoir during most years of the recent 5-year drought, and releases were made from the extremely depleted Shasta Reservoir to dilute this discharge and avoid catastrophic loss of fish life. The release of water from the Shasta Reservoir also reduced the available water storage for temperature control in the following summer for winter-run chinook.

In October 1994, the Minnesota Flats neutralization plant was completed which now fully treats the base and winter flows from the Richmond and Lawson, and Old/No.8 mine seep discharges (the three largest sources of contaminants). This plant replaces the emergency treatment plant and a copper cementation facility. Additional modifications are under consideration to enable the Minnesota Flats plants to also treat flows from the contaminated reaches of Slickrock Creek, and possibly Boulder Creek. The plant has improved the ability to control metal loadings to the river. During the winter storms in January-March 1995, this new plant prevented 200,000 pounds of copper and zinc from contaminating the Sacramento River. Further remedial actions are currently being considered, which are anticipated to further reduce metal loadings to the river. Although Basin Plan objectives have not yet been achieved, continued implementation of the EPA's Superfund Program is expected to remedy the heavy metal waste discharge from Iron Mountain Mine.

Other Point Sources of Pollution

Selenium in Carquinez Straits and Suisun Bay

Selenium is consistently present in the western Suisun Bay and Carquinez Straits (North Bay), regardless of river discharge, and largely has been attributed to industrial effluent from petroleum refineries (Cutter 1989). Selenium dissolves into water predominantly as selenite and selenate, and both forms are very stable. Effluents from municipal and industrial dischargers contain high concentrations of selenite, while selenium in San Joaquin River water is principally in the form of selenate. Loadings from municipal and industrial dischargers are sufficient to completely account for the selenite inputs into the North Bay during low flows (Cutter 1989). Studies have documented that selenium released from refineries and concentrated in tested mussels and oysters exceed the highest known concentrations for those species compared to 145 other stations sampled throughout the United States (San Francisco Bay Regional Water Quality Control Board 1992).

Effects on Winter-run Chinook. Several laboratory studies investigated the bioaccumulation of selenium in juvenile chinook (Hamilton and Wiedmeyer 1990, Hamilton et al. 1990, Hamilton et al. 1986). These studies attempted to mimic the selenium composition of San Joaquin Valley drainwater which has a higher ratio of selenate to selenite (about 6:1). Therefore, results from these studies are not directly comparable to selenite impacts potentially occurring in the North Bay. However, selenite impacts could be more detrimental, since selenite is more biologically available and more toxic to bivalves and phytoplankton than selenate (Fowler and Benayoun 1976, Pelletier 1986).

Hamilton et al. (1990) found that growth was significantly reduced in fish fed a diet with high selenium concentrations (35.4 ug/g) after a period of 90 days and 120 days. After 120 days, survival in these fish was also significantly reduced when given a seawater challenge. Although it is not clear how these results apply to selenium levels in the diet of winter-run chinook in their migration through the Delta and San Francisco Bay, the results indicate the potential for reduced growth and survival.

Existing Protective Measures. In 1990, the EPA listed the northern segments of San Francisco Bay as water quality impaired under Section 304(l) of the CWA due to excessive selenium levels. Petroleum refineries were required to curtail their selenium loadings to 5 parts per billion by December 1993 to improve water quality in this area. While three out of six refineries met the EPA criteria through implementing biological, chemical, and physical treatments of discharge, three refineries remained out of compliance. In subsequent litigation, a settlement agreement was reached which allowed the delinquent petroleum refineries an additional four and a half years to achieve EPA criteria for selenium in the Bay. The San Francisco Regional Water Quality Control Board has recommended more rigorous measures, specifically an additional 30% reduction in selenium levels to adequately protect the Bay's beneficial uses.

Other Municipal and Industrial Discharges. Municipal treatment plants are important point sources of pollution, because they release heavy metal contaminants, thermal pollution, pathogens, suspended solids, and other constituents. Within the Sacramento River drainage and Bay-Delta, there are three large municipal treatment plants: the West Sacramento Waste Discharge Plant, the Sacramento Regional Waste Treatment Plant, and Stockton Sewage Treatment Plant. Since the 1950s, primary treatment, secondary treatment and pretreatment programs have all reduced the volume of pollutant loadings to the river and estuary. For the most part, problems with odors, algal blooms and low oxygen levels are now corrected, however, heavy metal loadings and toxic organic pollutants, in particular, remain a source of major concern (San Francisco Estuary Project 1991).

Other important, point sources of pollution within critical habitat of winter-run chinook include the Simpson Mill near Redding which discharges polychlorinated biphenyls (PCBs), two oil terminals, three paper processors, four oil production facilities, and several manufacturing facilities which discharge into the Delta (State Lands Commission 1991).

Non-point Sources of Pollution

In a recent study which examined the uptake of contaminants by juvenile chinook salmon in San Francisco Bay, stomach contents of juveniles sampled from the Bay were found to contain elevated levels of polychlorinated biphenyls (PCBs) and other chlorinated pesticides, as did juveniles sampled from the Sacramento River Delta and from hatcheries (Varanasi et al. 1993). The source of the PCBs and other chlorinated pesticides in the system is not known, but it is likely that they stem in part from non-point sources.

In general, studies have demonstrated that juvenile chinook salmon migrating through polluted urban estuaries show increased body burden of a variety of toxic chemicals, including priority pollutants (McCain et al. 1990). Effects of these contaminants were found to be the suppression of immune competence (Arkoosh et al. 1991) and reduced growth.

Sedimentation and Associated Contamination

Sediments constitute nearly half of the materials introduced into rivers from nonpoint sources. Excess silt and other suspended solids are generated during storm events from plowed fields, construction and logging sites, and mined land. High influxes of sediments result in elevated turbidity which can clog juvenile chinook gills, smother benthic communities and alter their habitat, and decrease photosynthesis in aquatic plants. High rates of sedimentation also degrade salmon spawning habitat.

Stormwater runoff in urban and developing areas is another major source of sediments as well as contaminants. Runoff is generated as rain falls on hard impervious surfaces such as roads, roofs, and parking lots, and collects in puddles and runs across the land surface. Stormwater can accumulate or transport oil, trash, and street dust, while absorbing suspended solids laden with nutrients, heavy metals, toxic organics, and pathogens. Large volumes of stormwater can be generated in a short period of time and discharge pulses of sediment and contaminants through ditches and pipes directly into the Sacramento River system, Delta, and Bay.

In the Sacramento Valley, urban runoff contributes greater loads of trace metals than municipal and industrial dischargers, especially for lead and zinc. Stormwater runoff from the city of Sacramento has been found to be acutely toxic to aquatic invertebrates even at lower concentrations (3:1 dilution; 25% stormwater). Urban runoff during the dry season (May-October) may also be substantial, and is generated from domestic/commercial landscape irrigation, groundwater infiltration, pumped groundwater discharges, construction projects and wash-off practices. With increases in human population and increases in impervious surfaces, the threats from urban runoff to the health of the Sacramento River system, Delta, and Bay are substantial.

Agricultural Drainage

Sacramento River water is generally of good quality except in May and June when agricultural drainage may account for 30% of the flow (Gunther et al. 1989). The Colusa Basin Drain is the largest source of agricultural return flows to the Sacramento River. It originates north of the town of Willows, captures water from the two major water diverters, Tehama-Colusa and Glenn-Colusa Irrigation districts, and drains into the Sacramento River below Knights Landing. The drain has been identified as a major contributor of warm water, and a major source of pesticides, turbidity, suspended sediments, dissolved solids, nutrients, and trace metals.

The drain receives return water from one of the largest rice-growing areas in the Central Valley. Pesticides are intensively used in the area and include methyl parathion, carbofuran, malathion, molinate, thiobencarab, and bensulfuron methyl. In the past, Colusa Basin Drain water was demonstrated to be significantly toxic to zooplankton (*Neomysis mercedis*) due to lethal concentrations of methyl parathion (Finlayson et al. 1993). A herbicide control program began in the mid-1980s, and a insecticide control program was initiated in the early 1990s for Colusa Basin Drain. These programs, in conjunction with restricted diversions at the GCID pumping station, have facilitated the reduction of toxic drainage to about 10% of 1980s levels (L. Marshall, pers. comm.; B. Finlayson, pers. comm.). However, if higher pumping resumes at GCID, there is the potential for high concentrations of toxins in Colusa Basin Drain to resume.

In addition, the practice of spraying dormant orchards during the winter (to control summer insect populations) has been found to result in high toxicity run-off to the river. Most monitoring thus far has been conducted in the San Joaquin River and south Delta, but more monitoring is planned for the Sacramento River basin (L. Marshall, pers. comm.).

Dredging and Dredge Disposal

About 8 million cubic yards of sediment are dredged annually in the San Francisco Estuary. In addition, 19 million cubic yards of "one-time" dredging has been authorized by Congress for the Oakland Harbor, Richmond Harbor, John F. Baldwin ship channel, and two Navy projects. Dredging is conducted mainly by the USACOE, but also the U.S. Navy, ports, commercial marina operators, and local flood control and reclamation districts. Methods of dredging include clam-shell, "pothole" dredging, and suction dredging.

In recent years, most dredge materials have been disposed of at one of three in-Bay disposal sites: near Alcatraz Island, at Carquinez Strait, and in Central San Pablo Bay. Mounding at the primary disposal site, Alcatraz Island, has demonstrated the site's limited capacity and has caused navigation concerns. The impacts from commercial sand mining are also similar in nature to those from dredging for navigation. Therefore, sand mining is included in the following review of dredging impacts on winter-run chinook.

Effects on Winter-run Chinook. Dredging and dredge disposal temporarily increases turbidity, modifies nearshore shallow water habitat, and may affect the behavior and physiology of juvenile chinook salmon. It may also redistribute toxic pollutants and increase their availability to aquatic organisms, including juvenile salmon. The major effects of increased suspended sediment concentrations at disposal sites are probably on fish behavior, feeding patterns, foraging efficiency, modified prey response, and choice of habitat (San Francisco Estuary Project 1994).

Specifically, direct impacts to juvenile salmon are expected to be: 1) entrainment into suction dredge intake pipes; and 2) dispersal of migrating or foraging salmon schools by heavy turbidity plumes caused by inwater disposal. Indirect but cumulative effects include redistribution of disposed sediments on foraging habitat, redistribution of contaminants to foraging habitats, and changes in ecosystem biodiversity by continuous disposal actions.

Existing Protective Measures. Efforts are ongoing to establish a Long-Term Management Strategy (LTMS) for the placement of dredged material in the San Francisco Bay region. If successful, the volume of dredge-material disposed in the Bay will be greatly reduced. In particular, the LTMS will reduce or eliminate dredge-material disposal in the Carquinez Strait migration corridor.

Also, Section 404 of the CWA and Section 103 of the Marine Protection, Research, and Sanctuaries Act (MPRSA) gives the USACOE the primary authority to: 1) regulate dredging and disposal activities, 2) issue permits for discharge of dredged material into inland and near-coastal waters of the United States, and 3) permit the transportation of dredged material for dumping into coastal waters and open ocean. The CWA and MPRSA also assigns the EPA a major role in the management of dredged material, by granting the EPA authority to designate ocean disposal sites and to cooperate with the USACOE in the development of criteria for evaluation of environmental impacts of proposed disposal activities.

Section 404 of the CWA requires the EPA to perform similar functions in regulation of dredging activities in estuaries and other inland waters. The EPA, in cooperation with the USACOE, has developed guidelines for evaluation of environmental impacts of dredged material discharges and responsibility of reviewing permit applications and providing comments to the USACOE. The SWRCB and its nine Regional Water Quality Control Boards also regulate water quality in California, and are required to verify that dredged material discharge will not violate water quality standards under Section 401 of the CWA. The state McAteer-Petris Act (1965) created the San Francisco Bay Conservation and Development Commission and gave it permitting authority for dredging and filling activities in the San Francisco Bay. In addition, the State Lands Commission, which administers public trust lands in coastal waters and other tidal and submerged areas, must give authorization for dredge or dredge disposal.

With so many agencies involved in dredging and disposal management, a cooperative permitting framework has been established as part of implementing the LTMS. This framework includes the creation o a Pilot Dredged Material Management Office (DMMO), which has the goal of reducing redundancy and unnecessary delays in permit processing and increasing consensus decision-making among agency staffs. The DMMO also has the goals of assuring that: (1) the laws and policies of member agencies will be fully implemented; (2) full public review and input to the decision making process will be maintained; and (3) projects will be managed in an environmentally and economically sound manner. Agencies involved with DMMO include the San Francisco Bay Conservation and Development Commission, EPA, USACOE, SWRCB, Regional Water Quality Control Board for the San Francisco Bay Basin, and the State Lands Commission.

II. FACTORS AFFECTING JUVENILE AND ADULT PASSAGE

Several prominent structures in the Sacramento Valley may delay or block the upstream migration of adult winter-run chinook, and impair the downstream migration of juveniles. These include Keswick Dam, the Anderson-Cottonwood Irrigation District dam on the main stem Sacramento River near Redding, the Red Bluff Diversion Dam, the Glenn-Colusa Irrigation District's Hamilton City Pumping Plant, the Sacramento Deepwater Ship Channel, and the Suisun Marsh Salinity Control Structure.

Keswick Dam

Keswick Dam is located on the Sacramento River about nine miles downstream from Shasta Dam. The dam has no fish ladders and completely blocks the upstream passage of migrating adult winter-run chinook. The dam was designed as a flow control structure for the Sacramento River to stabilize water releases from Shasta Dam. Construction of the dam, spillway, fishtrap, and powerplant was completed in 1951. The dam is a concrete gravity structure 157 feet high with a crest of 1,046 feet, creating a reservoir with a capacity of 23,800 acre-feet.

The spillway is located on the east side of Keswick Dam and is used for flood releases and for releases during power plant outages. During normal operations, the stilling basin below the spillway is separated from the tailwater river channel by an end sill and a rock bench. The spillway end sill and spillway exit channel are normally at higher elevations than the downstream river channel. Therefore, the stilling basin is normally isolated from the river channel. However, during spill events, the spillway end sill and rock bench are inundated and the stilling basin becomes connected to the river channel. During spills, winter-run chinook have been attracted into the stilling basin. When the spill ended, the stilling basin became isolated from the river and adult salmon were unable to return to the river. Recent documented occurrences of spillage that entrapped salmon include: December 1990 (70 adult salmon), February 1992 (unknown number), September 1994 (15-17 adult salmon), October 1994 (18 adult salmon), February 1995 (2 late-fall-run chinook), April 1995 (24 winter-run chinook, 4 late-fall-run chinook), and May 1995 (21 winter-run chinook). Numerous other spills have occurred which were likely to entrap adult salmon, but water conditions were too turbid for observations.

Existing Protective Measures.

The NMFS 1993 Biological Opinion required that the USBR structurally modify the stilling basin to allow free passage of adult salmon from the basin back to the river. A proposed solution was developed, and agreed upon by NMFS, CDFG, USFWS and USBR, which involves excavating a channel from the stilling basin, through the spillway end sill and rock bench. This channel was constructed in 1995, but needs to be monitored to determine its effectiveness in allowing winter-run chinook salmon to return unharmed to the river.

Anderson-Cottonwood Irrigation District Dam

The Anderson-Cottonwood Irrigation District (ACID) dam on the main stem Sacramento River near Redding was built in 1917 and was the first dam constructed on the Sacramento River (RM 298.5). The dam is a 450-foot long flashboard type structure which raises the backwater level 10 feet. This seasonal dam has the capacity to divert 400 cfs or a total of about 175,000 acre-feet of water annually to its main canal. The dam is installed only during the irrigation season, which typically involves installing the flashboards in early April, and removing them as late as October or early November. The dam usually requires some adjustments during the irrigation season as well. The installation, removal and mid-season adjustments of the flashboards are coordinated with reductions in flow releases from Keswick Dam by the USBR. Because the dam's flashboards must be placed or removed manually, flows have been reduced to at least 5,000 cfs to allow personnel to safely adjust the flashboards. In the past, flows have been reduced by as much as 50% during the winter-run chinook incubation period to accommodate mid-season adjustments.

Effects on Winter-run Chinook.

Historically, the dam was a complete barrier to salmon until a poorly designed fish ladder was installed in 1927, which has remained in place. The fish ladder is on the north abutment, but it is very ineffective because the ladder is too narrow and its flow too low (60 cfs) to fully attract and pass upstream migrating fish. During the non-irrigation season, the dam is removed allowing free passage for salmon, but, beginning in April, the dam is installed which hinders the upstream migration of adult winter-run chinook salmon. Spawning conditions upstream of the ACID dam are good, and winter-run chinook would benefit from greater access to these spawning grounds between ACID and Keswick Dam (about 3 river miles).

Juvenile winter-run chinook move downstream at peak levels in September and October when flashboards are still installed. Juveniles migrate past the dam by either dropping as much as ten feet over the dam to the river below, or by moving through the bypass facility. In either case, the juveniles may become disoriented and more susceptible to predation. Predator abundances appear low at the dam, but more evaluations are needed. At the bypass facility, the screens do not operate consistently because they are light-weight. During higher flows and with higher debris loads, the screen panels open up and may entrain juvenile chinook. In addition, high volume releases from ACID's canal downstream of the dam can attract and strand adult salmon. Occasionally there have also been discharges of toxic herbicides from the canal into tributaries.

Existing Protective Measures

Various litigation settlement agreements have resulted in the ACID improving their facilities and operations to minimize biological impacts. A settlement agreement signed by the

District with NMFS, required the following measures:

> resolution of the juvenile stranding problem resulting from flashboard adjustments,
> installation of fish screens on the Bonneyview Pumping plant,
> operation of the Main Canal to prevent attracting adult chinook,
> development and implementation of a herbicide application plan to prevent pollution of streams from canal drainage.

Accordingly, the District has developed measures that improve adult passage; reduce attraction of adults into artificial channels; and reduce juvenile entrainment. These measures include: 1) implementing a rigorous procedure for controlling the discharge of polluted water (final herbicide policy approved September 5, 1996); 2) reducing attracting adults into the Parkview Avenue discharge through modifying dam operations; 3) installing a new fishway on the opposite side of the dam; and **4)** installing fish screens on the Bonneyview Pumping plant. The District has also developed a hydraulic model and rule curves for more efficient operation of the water control system. The District can now determine a setting at which they can deliver the full water demand in the canal, while reducing the need for mid-season adjustment of the flashboards. The District has also recently entered into an agreement with the USBR to not call for reductions below 6,000 cfs after flashboards are installed. Implementation of this agreement should reduce the potential for stranding and dewatering, but it does not eliminate the problem.

Red Bluff Diversion Dam

The Red Bluff Diversion Dam (RBDD) is located on the Sacramento River about 2 miles southeast of the city of Red Bluff. The dam gates are lowered seasonally creating a lake about 3 miles long which contains about 3,900 acre-feet of water. The Tehama-Colusa and Corning canals deliver water diverted from the lake at the RBDD for irrigation (U.S. Bureau of Reclamation 1992).

The dam, lake and canals are part of the Sacramento Canals Unit of the Central Valley Project. The unit provides irrigation water primarily to the counties of Tehama, Glenn, and Colusa in the Sacramento Valley.

The dam is a concrete structure 52 feet high and 740 feet long. It has 11 gates, each 18 feet high and 60 feet long, which are raised or lowered to control the level of Lake Red Bluff and enable gravity diversion into the Tehama-Colusa Canal. The diversion capacity of the system is 3,030 cfs.

Permanent fish ladders are located on each abutment of the dam. The steps of the fish ladders drop the water surfaces in the ladders in 1-foot increments as flows pass downstream. The flow capacity of each ladder is 88 cfs, but additional flow is added near the downstream ends of the ladders to better attract upstream migrating fish into the entrance of each fish ladder. The combined flows total to a capacity of 388 cfs from each ladder. A seasonal ladder in the center of the dam with a capacity of about 100 cfs has been installed and operated since 1984.

The entrainment of juvenile chinook is deterred by a state-of-the-art rotary drum fish screen located downstream from the diversion's headworks. Juveniles pass through the headworks, are screened from entering the canal, and then move into a bypass system, which returns fish to the river below the dam. This new "Downstream Migrant Fish Protection Facility" at the dam was completed in 1992, replacing the former ineffective fish louver and bypass system.

Effects on Winter-run Chinook.

The RBDD has substantially contributed to the decline of winter-run chinook by impairing adult and juvenile migration. A multi-agency five-year Fish Passage Action Program, conducted from 1983 to 1988, determined that delay and blockage of adult chinook salmon were severe, and predation by Sacramento squawfish (*Ptychocheilus grandis*) was the major source of mortality for juveniles (U.S. Fish and Wildlife Service 1988).

The fish ladders remain ineffective in allowing adult salmon to migrate upstream (Hallock et al. 1982, Vogel and Smith 1986, U.S. Fish and Wildlife Service 1987d, Vogel et al. 1988). In several radio-tagging studies of winter-run chinook, 43-44% of tagged winter-run chinook were blocked by the dam (Vogel et al. 1988, Hallock et al. 1982). Tagged winter-run chinook that eventually passed the dam were delayed by: an average of 125 hours (ranging from 2 to 854 hours) in one study (Vogel et al. 1988), and by an average of 437 hours (ranging from 24 to 960 hours) in a previous study (Hallock et al. 1982).

To help protect winter-run chinook, the dam gates have been raised for varying periods since the end of 1986 (Figure III-10). At present, the dam gates are in the raised position from September 15 through May 14, allowing free passage to about 85% of the spawning run (based on average run timing from 1982-1986). However, there may be intermittent gate closures of up to 10 days for one time per year. Raising the dam gates has likely reduced the number of redds being built below the dam (Table III- 6). The remaining portion of the run migrating upstream after May 15th is likely to be delayed or blocked from passing the dam.

Adults that are obstructed from passing the dam are forced to spawn downstream where temperature conditions are typically unsuitable during the spawning and incubation period. Temperatures of 56°F usually cannot be maintained below RBDD, without severely depleting Shasta carryover storage during the winter-run chinook incubation period, such that eggs and larvae usually experience 100% mortality.

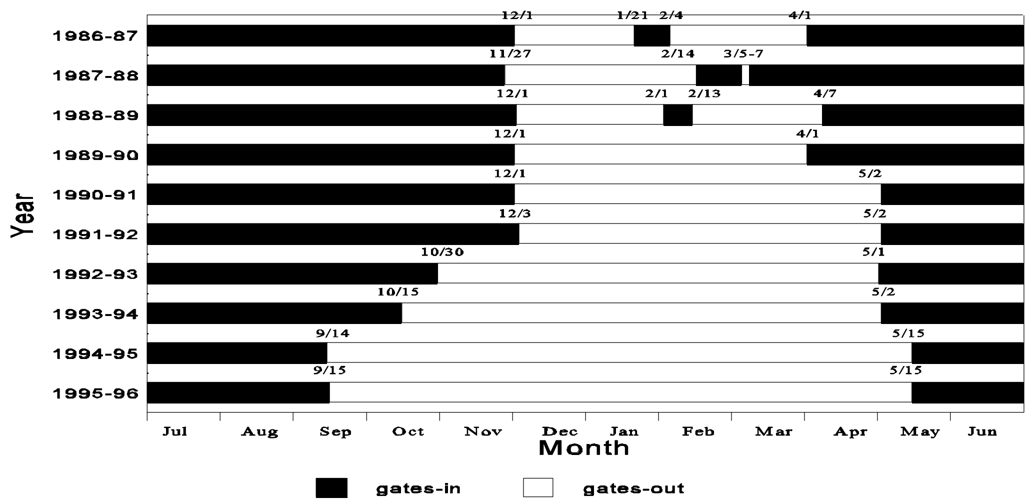
Table III-6. Estimated Redd Distribution by Percentage and River Reach for Winter-run Chinook in the Sacramento River. (California Department of Fish and Game Aerial Counts.)

River Reach	Percentage of Total Winter-run Chinook Salmon								
	198	198	198	199	1991	1992	1993	199	199
Keswick Dam to ACID	0.3	0.9	6.5	0.0	0.0	1.9	1.6	0.0	6.0
ACID to Hwy. 44	15.4	26.4	56.5	39.2	66.9	27.8	81.9	40.0	87.9
Hwy. 44 to Upper Anderson Bridge	16.6	25.8	19.6	46.4	33.3	40.7	13.4	20.0	5.0
Upper Anderson Bridge to Balls Ferry	18.9	6.8	2.2	5.1	0.0	14.8	0.8	33.3	0.0
Ball Ferry to Jelly's Ferry	28.6	4.2	0.0	2.1	0.0	5.6	0.8	0.0	0.5
Jelly's Ferry to Bend Bridge	14.2	8.9	13.0	0.0	0.0	5.6	0.8	6.7	0.0
Bend Bridge to RBDD	1.6	1.4	NS	0.0	0.0	0.0	0.0	0.0	0.0
Below RBDD	4.4	25.7	2.2*	5.1	0.0	3.7	0.8	0.0	0.5
Total # of Redds Estimated	318	1,297	46	97	12	54	127	15	199
NS = Not surveyed; *Reach between RBDD and Tehama not surveyed									

Adults, that must make repeated attempts to pass the dam but eventually are successful, undergo physiological stress which may contribute to their reduced fecundity. Because these adults are delayed in their migration, they are also likely to spawn farther downstream where suitable temperatures for spawning and incubation may not be attainable.

Juvenile chinook suffer mortality in passing the dam due to squawfish predation and disorientation or injury when passing beneath the dam gates or through the fish bypass system. Under the present schedule of gate operations, about 26% of the juvenile outmigrants must pass the dam when the gates are lowered in the water, and are susceptible to mortality associated with that passage. Vogel et al. (1988) released juvenile hatchery salmon above and below the dam to

Figure III-10. Historic gates-out operation of the Red Bluff Diversion Dam from 1986-present.



estimate total mortality during dam passage. He recaptured 16% to 55% less fish from the releases made above dam than below. The USFWS determined predation, primarily by squawfish, as the major cause of mortality to juvenile salmon migrating past the dam, whereas mortality due to physical injury from passing under the dam was minor (Vogel et al. 1988).

It is well-documented that winter-run chinook fry and smolts, which pass under the gates and into the turbulent waters below the dam, are heavily preyed upon by squawfish as well as striped bass (see Predation Section in this Chapter). Large concentrations of squawfish accumulate immediately below the dam, when juvenile winter-run chinook begin to migrate downstream during the late summer and early fall months (Garcia 1989). During this period, conditions for squawfish predation are optimal at RBDD, with low turbidity, low river flows and high river temperatures. Also, passage through Lake Red Bluff can delay downstream migrants and increase the opportunities for predation by birds and predatory fish (Vogel and Smith 1986).

The proportion of downstream migrants that are diverted into the canal headworks is estimated to be in direct proportion to the amount of river flow diverted into the canal (Vogel et al. 1988). Newly emerged winter-run chinook that encounter the dam during the peak irrigation season (July and August) are more likely to encounter high diversion rates, and thus, more fish may pass through the bypass facilities. As diversion rates decrease in September, more juvenile winter-run chinook should pass under the dam gates.

Passage through the bypass facilities may be preferable to under the dam gates.

Evaluations thus far indicate that the problems of entrainment have been alleviated by the new Downstream Migrant Fish Protection Facilities. Experimental data indicate that mortality due to passage through the former fish louver and bypass system was 1.6% to 4.1% (Vogel et al. 1988). Recent evaluations of the new system indicate that there is no significant immediate or delayed mortality associated with passage through the bypass system (Big Eagle et al. 1993, J. Bigelow, pers. comm.).

Existing Protective Measures.

The NMFS 1993 Biological Opinion requires the USBR to raise the RBDD gates from September 15 through May 14, allowing the majority of adult and juvenile winter-run chinook to pass the dam unimpeded. Other measures are being evaluated to further reduce or perhaps eliminate the need for lowering the dam gates. These include an Archimedes screw pump and a low-speed helical pump, which are being tested for their ability to divert water while protecting juvenile chinook. Preliminary results suggest that these pump technologies have very low injury and mortality rates. After a couple years of evaluation, the USBR will consider this among other long-term solutions to adult and juvenile passage problems at RBDD.

Glenn-Colusa Irrigation District Hamilton City Pumping Plant

The Glenn-Colusa Irrigation District (GCID) near Hamilton City operates the largest and oldest pumping plant on the Sacramento River, which has a pumping capacity of 3,000 cfs. The pumping plant's intake is located on an oxbow of the Sacramento River, with flows returning to the river via a bypass channel. Rotary fish screens were installed on the diversion by CDFG in 1972, however, they have never worked properly and do not meet the fish screen criteria developed by NMFS and CDFG. Problems with this screen became exacerbated when the Sacramento River streambed changed, which altered the hydrology of the oxbow's channel and further reduced the effectiveness of the fish screening system. In 1992, GCID modified the oxbow's channel adjacent to the fish screens and in the bypass channel, to improve hydraulic conditions for fish protection. GCID also installed flat-plate screens in front of the rotary screens (and trashracks) in 1993, as an interim measure to reduce salmon mortality until a long-term solution can be developed.

Effects on Winter-run Chinook

GCID may divert up to 20% of the Sacramento River. Assuming juvenile salmon are distributed with flow, up to 20% of the juveniles passing the GCID pumping plant may be subject to the impacts of the diversion. Alternatively, since salmon fry prefer bank habitat, juveniles may follow the river bank into the GCID oxbow such that up to 50% of the juveniles could be subject to the GCID diversion impacts. Juvenile winter-run chinook are exposed to the GCID pumping plant as early as mid-July, continuing through their peak downstream movement during late

August to early September, and into late November when the agriculture diversion season ends. In the future, this period of exposure to diversion could be extended through the winter, with implementation of the Riceland Habitat Joint Venture (See Section on Other Fish and Wildlife Management Programs in this Chapter).

Fisheries investigations since 1974 have documented fish losses in the vicinity of the District's pumping facilities. Decoto (1978) estimated from fyke net catches behind the fish screens that in excess of 300,000 chinook salmon juveniles were lost to the District's pumps from April 13 to July 26, 1975. Ward (1989) estimated that from 1972 to 1988, losses of juvenile chinook from all Sacramento runs in the oxbow probably ranged from 0.4 to 10.0 million fish annually. Of the four Sacramento river chinook races, winter-run chinook have probably been the most vulnerable to impacts from the District's pumping operations because newly emerged fry occur in the vicinity of GCID's water intake facility during the July through August period of high water diversions. Ward (1989) reported that 93% and 69% of the chinook captured at the screens from August through October in 1988 and 1989, respectively, were under 41 mm, and virtually all of these salmon were classified as winter-run chinook. Similarly, Decoto (1978) found that the mean fork length of chinook entrained by the screens in September was 32 mm, which classified them as winter-run chinook.

The overall adverse effects of the Hamilton City Pumping Plant include fish entrainment, poor passage conditions, and predation. The interim flat-plate screens are an improvement over the rotary drum screens, but are still likely to subject juvenile salmon to impingement due to high approach velocities at various points along the screen, inadequate sweeping-to-approach velocities, and long exposure times at the screens (U.S. Fish and Wildlife Service 1995). Predation is also likely in the vicinity of the screens (Vogel and Marine 1995). Additionally, flows in the bypass from the GCID diversion back to the Sacramento River are very poor, such that juvenile salmonids migration back to the river is slow and predation is probably considerable.

Existing Protective Measures

Attempts to remedy the impacts from the GCID diversion have been ongoing since the early 1980s. CDFG and GCID signed an agreement in 1987 to conduct studies to identify solutions to fish passage and water supply problems. A joint GCID/CDFG study was published in 1989, which recommended constructing an entirely new screening structure at the head of the existing intake channel, with a flat plate screen in a multiple "V" configuration.

In 1990, the USACOE entered into formal consultation with NMFS, pursuant to Section 7 of the ESA, on the potential impacts of the GCID dredge permit application on winter-run chinook. The resulting NMFS biological opinion concluded that operation of the GCID pumping plant was an interdependent and interrelated action and was likely to jeopardize the continued existence of winter-run chinook (National Marine Fisheries Service 1991b). NMFS submitted a reasonable and prudent alternative in the opinion to avoid jeopardy by constructing the screening structure recommended in the GCID/CDFG study.

GCID did not accept NMFS's alternative and was not issued a dredge permit by the USACOE in 1991. In June 1991, NMFS informed GCID that without the USACOE permit, GCID did not have authorization to "take" winter-run chinook at their pumping plant. GCID again did not pursue "take" authorization, by accepting NMFS's reasonable and prudent alternative in the USACOE permit or applying for an ESA section 10 take permit. Subsequently, NMFS sought injunctive relief in Federal Court. The Federal Court issued a temporary restraining order in August 1991 which limited GCID pumping to a level that would improve protection for winter-run fry and juveniles.

NMFS returned to Federal Court seeking a permanent injunction until GCID complied with the ESA. On January 9, 1992 a permanent injunction was ordered by the Federal Court enjoining GCID from pumping water from the Sacramento River when winter-run chinook may be present. In March 1992, GCID, NMFS, and CDFG entered into a court approved joint stipulation, which obligated GCID to improve hydraulic conditions for fish passage in the oxbow's intake and bypass channels. It also allowed GCID to pump at reduced levels while juvenile winter-run chinook are present until new fish screen facilities are completed.

When the 1992 joint stipulation expired in February 1993, a new joint stipulation was adopted in July 1993, requiring GCID to complete a long-term solution for protection of winter-run chinook through development of all necessary environmental analysis, selection, design, and construction. Also in 1993, the USBR was given responsibility for assisting in the funding of a screen at GCID with the passage of the CVPIA (P.L. 102-575). The environmental analysis and planning must be completed before the new screens are installed. A draft EIS/EIRfor the long-term solution is scheduled for release in 1997. The USBR will also be developing designs for the fish screens, and preparing for construction, which is scheduled for completion in 2000. In the interim period, GCID is required by NMFS to comply with numerous measures, which include the following:

Maintaining 500 cfs flow in the bypass through the lower oxbow when Sacramento River flow exceeds 4,000 cfs, and 200 cfs flow in the bypass when the Sacramento River flow is less than 4,000 cfs, between August 1 and November 30, if dredging has occurred that year;

Maintaining 500 cfs flow in the bypass through the lower oxbow when Sacramento River flow exceeds 8,000 cfs, at least 300 cfs flow in the bypass when the Sacramento River flow is from 8,000 to 4,000 cfs, and 200 cfs flow in the bypass when the Sacramento River flow is less than 4,000 cfs, between August 1 and November 30, if dredging has not occurred that year;

Operating the pumping facility such that the average screen approach velocity does not exceed 0.33 feet per second from August 1 through November 30.

Sacramento Deep Water Ship Channel

Sacramento River water is diverted into the Sacramento Deep Water Ship Channel, which may also divert juvenile winter-run chinook. Water quality, flow levels and rearing conditions in the channel are extremely poor, and may reduce the survival of juvenile winter-run chinook. Adult fall-run chinook have been caught close to the locks at the upstream end of the channel, and have also been observed to be blocked from migrating upstream by the locks. Similarly, adult winter-run chinook may be attracted into the ship channel, and blocked from migrating upstream.

In addition, the USACOE has considered increasing the numbers of downstream migrants diverted into the Sacramento Deep Water Ship Channel. The concept is to improve fish survival by developing an alternative migration route that avoids exposure of juveniles to water export facilities, and diversions and other problems in the central and southern Delta. However, flows in the channel are extremely low to stagnant, and at least 2-3 feet-per-second velocity would be needed to move juvenile salmon down the channel. To achieve this minimum flow, an estimated 27,000 cfs would have to be diverted from the Sacramento River, given the cross-section of the ship channel. This rate is more than the typical flow of the Sacramento River. Clearly, the natural migration routes of chinook should be restored to improve downstream survival, rather than artificial waterways where habitat conditions are poor. The USACOE is currently assessing options to allow adult passage from the Sacramento Deep Water Ship Channel, including a fish ladder.

Suisun Marsh Salinity Control Structure

Suisun Marsh is one of the largest contiguous brackish water tidal marshes in the United States and is situated west of the Sacramento-San Joaquin Delta and north of Suisun Bay. It encompasses more than 10% of California's remaining natural wetlands. In 1978, the SWRCB established channel water salinity standards for Suisun Marsh in Decision 1485. Those standards were designed to provide optimum habitat for waterfowl food plant production and to preserve the Suisun Marsh as a brackish water tidal marsh. In 1984, the CDWR published the "Plan of Protection for the Suisun Marsh", which included an environmental impact report prepared in cooperation with the CDFG, Suisun Resource Conservation District, and the USBR. The plan contained a proposal for implementing elements to monitor water quality, manage diked wetlands, and install facilities to improve the water quality of the inner marsh. Subsequently, the agencies completed the Morrow Island distribution system, Roaring River distribution system, the Goodyear Slough outfall, and the Suisun Marsh Salinity Control Structure.

The Salinity Control Structure gates are operated from October through May, to meet water quality standards, by closing on flood tides and opening on ebb tides. Under "full-bore" operations, the gates are opened and closed on both daily tidal cycles to increase the quantity of freshwater entering the slough. Operations of the gates varies depending on water year type, such that gates are typically operated full-bore during dryer years while gates are usually up in wet years. Stoplogs are also placed adjacent to the gates to help close off the slough in order to operate the gates.

Effects on Winter-run Chinook

The Salinity Control Structure may delay and block adult upstream migration and affect juvenile downstream migrants. Operation of the Salinity Control Structure reverses the net tidal flow within Montezuma Slough from a net eastward to a net westward flow. The altered hydrologic conditions may increase the attraction of adult chinook into the slough. Adult winter-run chinook entering the lower end of Montezuma Slough may be blocked or hindered by operation of the gates as they attempt to return to the Sacramento River.

Two studies have been conducted to assess the effects of the structure's operations on adult salmon passage (Tillman et al. 1996; Edwards and Urquhart 1996). These studies evaluated fish passage under three conditions or phases: (1) gates raised and flashboards out (structure not operational); (2) flahsboards in and gates raised; and (3) gates fully operational. In both studies, fall chinook salmon were used. Results from the first study in 1993 indicated that 91% of the adults passed the structure during phase I; 47% during phase II; and 50% during phase III. In the 1994 study, results indicated that 78% of adults passed the structure in phase I; 45% in phase II; and 58% in phase III.

The 1993 study also showed a significant difference in fish passage times between operational phases. On average, fish passed the structure within 12 hours during phase I; 23 hours in phase II; and 25 hours in phase III. In the 1994 study, fish passage times varied somewhat with adults passing within an average of 58 hours during phase I; 61 hours during phase II; and 88 hours during phase III. These data indicate that the Salinity Control Structure both delays and blocks the upmigration of adult winter-run chinook.

Juveniles naturally migrate into Montezuma Slough and through the various waterways in the Suisun Marsh. However, operations of the Salinity Control Structure may substantially increase the number of juveniles entering the slough. Juvenile survival in Suisun Marsh sloughs is presumed to be reduced due to the large number of unscreened water diversions (over 300). Also, predator abundance has increased at the Salinity Control Structure since its installation and commencement of operations (California Department of Fish and Game 1994c; see also Predation Section in this Chapter). Higher predator abundance suggests increased predation on juvenile chinook, as operation of the Salinity Control Structure provides predatory fish with shadows and turbulence for ambushing prey.

Fisheries studies with marked fall-run chinook have suggested that only 0.76% to 2.74%

of juvenile salmon migrate into Montezuma Slough, under varying gate operations (Table III-7). However, these estimates may not reflect the full range because surveys were conducted in the spring when the amount of water diverted into the slough tends to be less. Also, estimates were made by comparing the density of juvenile fall-run chinook in sampling with mid-water trawling at Montezuma Slough and at Chipps Island. Mid-water trawling at Chipps is estimated to sample only about 0.76% of the water column, whereas a larger portion (5%) of Montezuma Slough can be sampled. Hence, these results are influenced by the ability to estimate juvenile chinook abundance at Chipps Island, and the degree and direction of bias is unknown.

Table III-7. U.S. Fish and Wildlife Service Studies of the Percentage of Juvenile Chinook Salmon Entering Montezuma Slough Compared to Chipps Island.

Date	Average % salmon in Montezuma	Range in values (%)	Number of samples (n)	Operations of Salinity Control Structure
April 6 - May 28, 1987	0.81	0.17 to 2.72	28	Pre-project
April 20 - May 1, 1992	0.76	0.19 to 1.56	9	Full-bore
May 12 - May 25, 1993	2.74	0.58 to 5.68	10	3 Gates up, stop logs in place

Alternatively, the proportion of juvenile chinook entering Montezuma Slough may be estimated by assuming that salmon move in direct proportion to flow splits between Montezuma Slough and the Sacramento River. Using this assumption, the proportion of salmon entering the slough may vary from 4 to 36% on an average monthly basis during the winter-run chinook outmigration period (Table III-8). The proportion of flow entering Montezuma slough may be higher in dry years, and lower in wet years
.

Existing Protective Measures

In 1985, the USACOE issued a permit to the CDWR, pursuant to Section 10 of the Rivers and Harbors Act and section 404 of the Clean Water Act, authorizing the construction of the Suisun Marsh Salinity Control Structure. Due to concerns raised by the EPA, USFWS and NMFS, the USACOE included a number of special conditions in the permit to address potential impacts on migratory fish species. These conditions included requiring CDWR: 1) to develop a monitoring program to describe the effects of the Structure on the aquatic environment, including

Table III-8. Percent of Flow Entering Montezuma Slough Under "full-bore" Gates Operation During Winter-run Outmigration Period as Modeled for a Wet Year 1992/1993, and a Dry Year 1993/1994. (Note that the SCS gates were actually opened from late January to May 1993, such that percent diverted was probably less in this year.)

Month	Percent of Flow into Montezuma Slough	
	Wet Year	Dry Year
December	20%	26%
January	5%	36%
February	5%	8%
March	4%	14%
April	4%	26%

a monitoring program to determine the magnitude and nature of delays and predation losses to migratory fish; and 2) to mitigate the effects by modifying operations of the Structure, design of the Structure; or other measures.

Subsequently, NMFS in its 1993 Biological Opinion on the CVP/SWP operations also required that a fisheries monitoring program be developed and implemented to evaluate the impacts of the control structure. These studies include evaluating the following: 1) the diversion rate of juvenile salmon into Montezuma Slough, 2) the predation rate on juveniles at the control structure, 3) juvenile survival rates during passage through Montezuma Slough, and 4) the upstream passage of adult chinook past the control structure.

To date, the CDWR have conducted studies on predation which were initiated in 1987 and studies on adult passage which were not initiated until 1993. These studies should provide sufficient information to assess the potential adverse effects of the control structure.

NMFS also initially required in the CVP/SWP Biological Opinion that either the Salinity Control gates be closed from March 1 through April 15, or that unscreened diversions in the slough not be operated during this period. Accordingly, unscreened diversions did not divert water during the specified period in 1993. This requirement was lifted for several years, in order to conduct further fisheries studies, but a similar requirement was reinstituted through a different USACOE permit issued to the Suisun Resource Conservation District.

Entrainment

Entrainment is defined as redirection of fish from their natural migratory pathway into areas or pathways not normally used. Entrainment also includes the take, or removal, of juvenile fish from their habitat through the operation of water diversion devices and structures such as siphons, pumps, and gravity diversions.

A primary source of entrainment is unscreened or inadequately screened diversions. These diversions range from small siphons, diverting 20 cfs or less, to the large export facilities operated by the USBR and the CDWR in the southern Delta that have the combined capacity to pump approximately 12,000 cfs of water daily. According to a 1987 report by the California Advisory Committee on Salmon and Steelhead Trout, there are more than 300 unscreened irrigation, industrial, and municipal water supply diversions along the Sacramento River within the designated winter-run chinook critical habitat reach between Redding and Sacramento. These 300 diversions annually divert nearly 1.2 MAF from April through October. A more recent survey by CDFG identified 350 unscreened diversion along the Sacramento River below Hamilton City (D. Odenweller, pers. comm.).

An unpublished examination of the possible impacts of local agricultural diversions in the Delta for CDWR identified about 1,800 small unscreened diversions in the Delta (Brown 1983). A more recent survey by the CDFG indicated that a minimum of 2,050 unscreened diversions were present (D. Odenweller, pers. comm.). The CDWR estimated the average size of the intakes for these pumps and siphons was 10-12 inches with low average flows. These diversions, combined with local precipitation and levee seepage, result in a total Delta annual consumptive use of water of about 1.65 MAF.

Effects on Winter-run Chinook Salmon.

Entrainment of juvenile winter-run chinook is one of the most ubiquitous causes of mortality in the Sacramento River and Sacramento-San Joaquin Delta. Entrainment of juveniles occurs in the Sacramento River above Colusa during their in-river residency, in the lower river during later rearing and emigration, and in the Delta during further residency, rearing, and emigration. At this time, an estimate has not been made on the total losses of juvenile winter-run chinook occurring due to entrainment. However, Hallock (1987) estimated that about 10 million juvenile salmonids are lost annually to unscreened diversions in the Sacramento River, primarily between Ord Ferry and Knights Landing.

The stream reach above Hamilton City has not yet been surveyed. The more than 350 unscreened diversions in the Sacramento River may be causing important losses of juvenile winter-run chinook as juveniles rear in the Sacramento River for a large portion of the normal irrigation season, typically July through November. In addition, the recent implementation of a program to flood rice field stubble during the winter is adding to the potential for entrainment. This new program has extended the time during which juveniles are susceptible to entrainment.

The more than 2,050 unscreened diversions in the Delta also have an important potential to entrain juvenile winter-run chinook. However, the magnitude of these diversions, and the extent to which these diversions cause substantial juvenile losses has not been adequately studied.

Existing Protective Measures

NMFS and CDFG have undertaken a number of actions to reduce the loss of juvenile winter-run chinook at major diversions within the Sacramento River and Delta as described below:

- ACID installed three water-intake screens on the previously unscreened Churn Creek Pump Station in 1992 in response to an enforcement action taken by the NMFS pursuant to violations of the ESA.

- The USBR completed the Tehama-Colusa Canal fish screen facilities in 1990 to eliminate fish entrainment into the Tehama-Colusa and Corning irrigation canals and to reduce predation at the RBDD.

- A Federal court approved joint stipulation obligated GCID to improve hydraulic conditions for fish passage in its intake and bypass channels.

- Some limitations were imposed on operation of the Delta Cross Channel gates, reducing the diversion of juvenile winter-run chinook from the Sacramento River into the central and southern Delta (National Marine Fisheries Service 1993a, National Marine Fisheries Service 1995a).

- USFWS and NMFS issued Section 7 biological opinions to the USACOE for maintenance activities by the Suisun Resource Conservation District, promoting the screening of diversions within Suisun Marsh, which number over 300.

- On May 10, 1993, NMFS requested that the USACOE San Francisco and Sacramento Districts provide an inventory of all Sacramento River and Delta diversions and discharges that have permits under Section 10 of the Rivers and Harbors Act and/or Section 404 of the CWA.

- NMFS published an advanced notice of proposed rulemaking to establish screening requirements for water diversions from the Sacramento River and Delta to protect winter-run chinook (National Marine Fisheries Service 1993b). If a rulemaking for screening diversions is deemed appropriate, NMFS will publish a draft rulemaking which outlines potential measures for screening, and then a final rulemaking.

In addition, the USBR is implementing a screen demonstration program that may advance the technology and acceptance of screens and other protective devices in the Sacramento River. Funds from the Drought Act of 1991 will be used for the installation of a number of fish screening devices for diversion facilities on the Sacramento River for the purpose of demonstrating their effectiveness.

In a separate Section 7 consultation, NMFS and the USFWS issued biological opinions to the USACOE in 1994 on the Suisun Resource Conservation District's maintenance activities in the marsh. As a result, unscreened intakes in various sloughs in the marsh are not permitted to divert water from February 21 through March 31 to protect winter-run chinook. To protect Delta smelt, there are restrictions in diverting water from unscreened intakes from April 1 through May in wet years. These restrictions will be lifted when intakes in the marsh are properly screened. In 1995, the SRCD initiated a Suisun Marsh Diversion Screening Program which includes a plan to eliminate, downsize, and consolidate and screen diversions. Five to ten diversions are slated for screening in the near future.

Pursuant to the CVPIA, the Anadromous Fish Screening Program has also been initiated to screen diversions, rehabilitate existing screens, replace non-functioning screens, and relocate diversions to less fishery-sensitive areas (Section 3406(b)(21) of the CVPIA). The USFWS, in cooperation with the USBR, is responsible for assisting the State of California in developing and implementing this long-term screening program and will work with other State and Federal resource and regulatory agencies.

III. POTENTIAL IMPACTS FROM THE WINTER-RUN CHINOOK ARTIFICIAL PROPAGATION PROGRAM

Because of the precipitous decline in the size of the winter-run chinook run during the 1980s, an artificial propagation program for the winter-run chinook was initiated in 1989 by the USFWS's Coleman National Fish Hatchery (CNFH). The first releases of hatchery-spawned fry into the upper Sacramento River were made in 1990. In addition to direct supplementation, the CNFH sends about 1,000 progeny each year to the Bodega Marine Laboratory and the Steinhart Aquarium for captive rearing. A portion of these progeny succumb, and the remaining fish are reared until sexual maturity. The purpose of this captive brood stock program is to produce juvenile winter-run chinook in the event of a complete failure of natural spawning, or otherwise to provide additional gametes to the supplementation program. Both the artificial propagation and captive brood stock programs are temporary measures that will cease once the natural winter-run population has recovered by amelioration of the habitat problems.

Potential Effects on Winter-run Chinook. The Winter-run Chinook Artificial Propagation Program is designed to augment the wild population while avoiding adverse genetic impacts. Nevertheless, there are risks involved with the artificial supplementation and captive breeding of the winter-run chinook population. Several unanticipated problems have recently been detected in the artificial propagation program. The first observations of hatchery winter-run chinook returning to the river occurred in 1995, but the hatchery adults appeared to return to spawn in Battle Creek alone and not to the main stem Sacramento River. Agency biologists have concluded that the hatchery produced winter-run chinook imprinted on Battle Creek water where the Coleman National Fish Hatchery is located. Instream conditions in Battle Creek, however, are too warm over the summer to expect successful production from these winter-run chinook. Moreover, the purpose of the program is to supplement the wild winter-run chinook population in the Sacramento River, not to establish a hatchery population in a tributary. Measures need to be implemented for future activities to ensure that hatchery-produced juveniles successfully imprint on the Sacramento River.

Also in 1995, information was developed to suggest that a few winter-run chinook have been inadvertently crossed with spring-run chinook in the artificial propagation program. Adults are collected for the propagation program based on timing and maturity of individual fish. In 1995 however, many of the collected adults were not maturing as expected, and genetics analyses were subsequently conducted to evaluate the identity of the spawned and unspawned broodstock. Results from this research suggest that the non-maturing broodstock were spring-run chinook, and that the spawned broodstock were a mixture of winter-run and spring-run chinook (D. Hedgecock et al., in review). Thus, in spite of the care taken in broodstock selection, genetic analyses show that spring-run chinook have been misidentified as winter-run chinook and used for hatchery propagation in 1993, 1994 and 1995.

Hybrids were released in 1993 and 1994. As a worst-case scenario, it is estimated that up to 26% of all juvenile salmon released in 1993 may have been hybrids (S. Hamelberg, pers. comm.). Suspected hybrid juveniles from the 1995 broodyear were not released to the river, however, to avoid the potential for compromising the genetic integrity of the wild population. Hybridization was not evident in the 1991 and 1992 broodyears. In the future, genetic testing protocols need to be implemented to positively identity adult chinook as winter-run chinook before crosses are made.

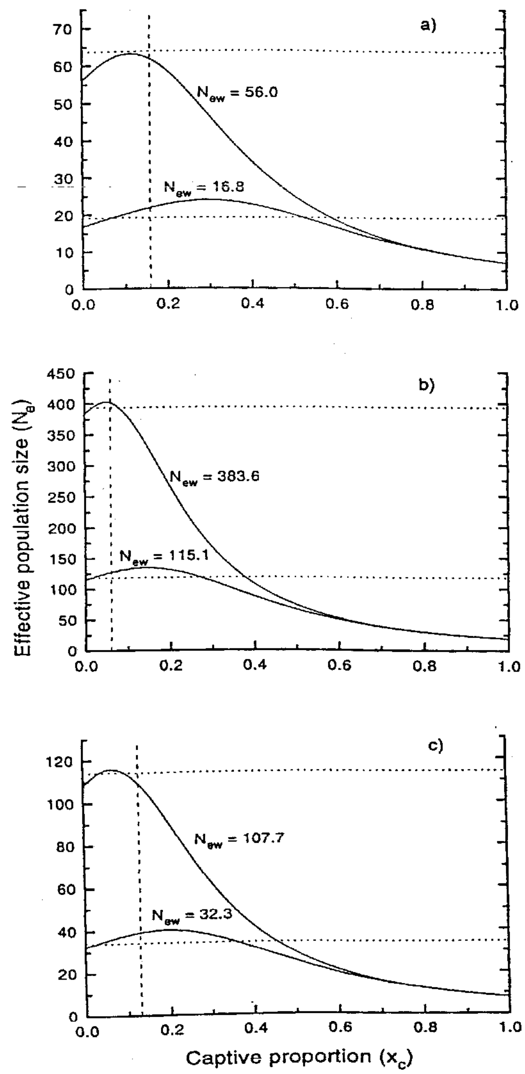
Another issue, in general, is the potential for artificial propagation to reduce the effective population size of the naturally spawning population. A theoretical treatment of such genetic effects was given by Ryman and Laikre (1991), who determined the overall effective size of mixed hatchery-reared and naturally spawned populations. This work showed that supplementation may, under certain circumstances, decrease the overall effective population size. The greatest danger of such a reduction in overall effective population size occurs when the effective population size of the natural portion of the population is small, the contribution from artificial propagation is large, and the effective population size of the artificially propagated individuals is small. These are the very circumstances that might occur in the case of a threatened or endangered salmonid species, for which aggressive hatchery augmentation programs are often proposed.

Hedrick et al. (1995) applied Ryman and Laikre's (1991) theory to the winter-run chinook supplementation program, by first calculating effective sizes of hatchery-produced smolt populations from Coleman National Fish Hatchery records of the numbers of males and females spawned and smolts produced by each pairwise mating. Effective population sizes for the hatchery component were 7.0 in 1991, 19.1 in 1992, and 7.7 in 1993. The effective size of the natural (or wild) population N_e is not known but upper and lower bounds are estimated, from indirect genetic estimates of effective size for wild winter-run (Bartley et al. 1992) and Snake River chinook populations (Waples, pers. comm.), to be between one-tenth and one-third of the run size in each year. The overall effective population sizes for the artificially augmented populations of winter-run chinook in the years 1991-1993 are plotted in Figure III-11 as a function of the proportion, x_c, of the population contributed by the hatchery. Here the upper and lower curves use the upper and lower bounds of the estimated effective sizes of the wild population.

The horizontal dotted lines in these figures show what the effective population sizes would have been at the upper and lower bounds of wild population size if no supplementation had been done. The vertical dotted lines intersect the curves showing overall effective population sizes at the estimated levels of actual supplementation. The supportive breeding program appears not to be dramatically reducing the overall effective population size, as Ryman and Laikre (1991) had suggested could happen. On the contrary, the supportive breeding program may have marginally increased the effective population size, in 1992 above what it would have been had all spawning winter-run been left in the river.

The potential impact of the captive broodstock program has not yet been investigated. A population genetic model for the combined artificial propagation and captive broodstock programs is under development by the Genetics Subcommittee of the Captive Broodstock

Figure III-11. Estimated Effective Population size (N_e) for the 1991 (a), 1992 (b), and 1993 (c) Return Years for the Upper and Lower Bounds of the Effective Population Sizes of Wild Population N_{ew} (Hedrick et al. 1995).



Program. This effort should be maintained over the course of these artificial propagation programs. Empirical genetic data, using highly polymorphic DNA markers such as simple tandem repeat polymorphisms, should be used to verify the effective size of the artificially augmented winter-run chinook population.

There are at least three methods for indirectly estimating N_e from genetic data: 1) a method based on changes in allelic frequencies over time (Krimbas and Tsakas 1971; Nei and Tajima 1981; Pollak 1983; Waples 1989); 2) a method based on the degree of non-independence of genotypic frequencies at two or more loci (called linkage or gametic-phase disequilibrium) in cohorts of juveniles (Hill 1981; Waples 1991a); and 3) a new method based on excesses in the proportion of heterozygous genotypes, relative to random mating proportions, in cohorts produced from limited numbers of males and females (Pudovkin, Zaykin and Hedgecock, in prep.). The first two methods have been applied to Pacific salmon, using allozyme markers (Waples 1990a,b; Bartley et al. 1992). The precision of all three methods should be improved by the availability of highly polymorphic nuclear DNA markers in winter-run chinook (Hedgecock et al. 1995; Banks et al. 1995).

Artificial selection in the hatchery should be limited to the greatest extent possible through developing appropriate identification techniques, fish culture regimes and release strategies, and minimizing mortality. Diseases present in or exacerbated by the hatchery environment are one obvious difference from wild selection regimes. Yet, there is no evidence for differential survival among the twelve families of 1991 brood-year, captive-brood stock held at the Bodega Marine Laboratory, despite nearly a 10% survival of this cohort from 1991 to 1994. Losses are likely a result from increased stress and disease in captivity (D. Hedgecock pers. comm.).

Existing Protection Measures. In June 1990, after the emergency and proposed listing of winter-run chinook, the USFWS submitted a Section 10 research permit application to NMFS for authorization to conduct various research activities, including the artificial propagation program. In August 1991, NMFS issued a Section 10 research permit to the USFWS authorizing the program through December 31, 1995, which was extended into 1996. The USFWS submitted a permit application to renew authorization for their artificial propagation program, which is presently under review by NMFS.

The USFWS voluntarily placed a moratorium on the take of winter-run broodstock during 1996 in order to assess the imprinting problem and allow development of additional genetic markers for identification of winter-run and spring-run chinook. At present, the USFWS is evaluating establishing a rearing facility on the Sacramento River to ensure juvenile winter-run chinook imprint on the mainstem. Also, a run identification model using six or more genetic markers is under development and expected to be completed by the end of 1996. This model will include statistical reliability estimates for all run determinations. All adult fish captured for use as broodstock would be genetically screened prior to their use in the winter-run chinook artificial propagation program.

IV. HARVEST IMPACTS ON WINTER-RUN CHINOOK

Ocean Salmon Fishery

In the Pacific states, chinook salmon are harvested regularly from Monterey northward to Kotzebue Sound, Alaska, and appear occasionally in landings in southern California (Emmett et al. 1991). Salmon fisheries are particularly important, economically and culturally, to the coastal communities north of Monterey. Besides commercial fisheries and their support activities, much of the tourist industry of these communities depends on recreational salmon fisheries. Salmon are also harvested in river by recreational anglers during their upstream spawning migration.

Effects on Winter-run Chinook. The majority of fishery impacts on Central Valley salmon stocks occur in the recreational and commercial hook-and-line fisheries off the coasts of California and Oregon (Allen and Hassler 1986). Salmon stocks intermingle in the ocean, and as individual fish are encountered in ocean catch, their stock identity is indeterminable morphologically. This makes it difficult to assess the direct fishery impacts on specific stocks such as winter-run chinook, however, several marking studies have provided fishery information.

Fin-clip studies. Inferences of fishery impacts and estimates of life history parameters have been largely based on tagging studies with winter-run chinook from 1969 to 1971. Wild juveniles from the 1969, 1970 and 1971 broods were seined in the upper Sacramento River and marked with a fin-clip (Hallock and Reisenbichler 1980). Marked winter-run chinook were subsequently recovered in the ocean fishery and in the Sacramento River at the RBDD.

Data from the fin clip study suggest that the ocean distribution of winter-run chinook is concentrated in California: 89% caught within state waters, and 11% in Oregon and Washington (Hallock and Reisenbichler 1980). Of those fish caught in California, the majority are caught in the San Francisco and Monterey areas (77%) and fewer off the northern ports of Fort Bragg, Eureka, and Crescent City (23%). The distribution of fish caught in the commercial and sport fisheries reflect the magnitude of the fishery landings at the time of the study, with most sport fish caught off San Francisco and Monterey, and the commercially caught fish landed primarily in Fort Bragg, Eureka, and Crescent City.

There were deficiencies with this fin-clip study, which contribute some unknown level of bias to the data. During the 1969-1971 tagging study, similar fin clips were applied to both the 1969 winter-run chinook and the 1968 brood spring-run chinook at the Trinity River Hatchery. This overlap would attribute higher amounts of marked returns to winter-run chinook, and overestimate fishing impacts on winter-run chinook (National Marine Fisheries Service 1986). Also, a small proportion of Sacramento River late-fall-run chinook were marked in addition to the winter-run, such that results apply to an unknown mixture. Finally, very low ocean recoveries were observed for the 1971 winter-run chinook brood.

Using data from this fin-clip study, impacts of the ocean salmon fisheries on winter-run chinook have been evaluated with a spreadsheet model developed by CDFG (California Department of Fish and Game 1989). The Winter-run Chinook Ocean Harvest Model was developed for use in evaluating the impacts of ocean fishery regulation options on Sacramento River winter-run chinook salmon. The model allows for analysis of a wide range of allowable fishing periods and minimum size limits and produces fishery impact estimates by fishery, general area, and stock of fish, including ocean escapement of winter-run chinook salmon. The major utility of this model is to compare relative impacts of regulation options, rather than actual impacts, because of the difficulty in projecting ocean abundance of California chinook salmon stocks. In the model, the recovery patterns from the fin-clipped broods are combined and partitioned into season and area parameters (time-area cells). Ocean impact rates in the base period (years in which fin-clipped 1969 and 1970 brood fish were recovered) are estimated by cohort analysis, and the model calibrated to reproduce the pattern of recoveries in the base period.

Some regulatory changes have occurred in the ocean salmon fishery since the fin-clip study was conducted. In 1984, the minimum size limit for the ocean recreational fishery limit in California was changed from 22 in. (55.9 cm) to 20 in. (50.8 cm), and the bag limit was reduced from 3 to 2 fish.[1] Effects of regulatory changes to minimum size limits or allowable fishing periods are evaluated by incorporating the predicted effect of such changes, relative to the regulations in the base period, as multipliers in time-area cells. The model simulates the fate of a single cohort of salmon subject to the modeled regulatory regime. Thus, it assumes that the same regulations have been in place over the lifetime of that cohort.

Recent CWT studies. Coded-wire tags are typically applied to hatchery fish and then used to assess ocean harvest impacts on salmon. Because winter-run chinook were not reared in hatcheries in the past, CWT studies have not been conducted until recently. With the decline of winter-run chinook in the late 1980s, the USFWS began culturing winter-run chinook and released some groups of coded-wire tagged fish, but with extremely low return rates. In 1991, the USFWS began marking all of the winter-run chinook smolts released from Coleman National Fish Hatchery with CWTs. The number of fish produced and tagged thus far has been relatively small: about 11,000 in 1991, 30,000 in 1992, 19,000 in 1993, 43,000 in 1994, 50,000 in 1995, and about 5,000 in 1996. This compares to 50,000-100,000 from typical releases of CWT hatchery chinook from other Central Valley runs over many years. Hence, CWT recoveries from these small release groups of winter-run chinook cannot provide statistically robust data on ocean harvest. They can only verify the incidence of harvest and provide a rough approximation of present ocean harvest impacts.

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[1] The size limit for the commercial troll fisheries has remained the same at 26 in. (66.0 cm) total length.

During the 1993, 1994, 1995 and 1996 ocean salmon fishing seasons, CWTs from winter-run chinook were recovered in the ocean in the California Department of Fish and Game's fishing port monitoring program (U.S. Fish and Wildlife Service 1996a). When expanded for sampling rate, the number of winter-run chinook CWTs recovered is estimated as follows: 1) 12 from the 1991 broodyear in the 1993 fishery; 2) 104 from the 1992 broodyear and three from the 1991 broodyear in the 1994 fishery; 3) 22 from the 1993 broodyear in the 1995 fishery; and 4) 8 from the 1994 broodyear and 5 from the 1993 broodyear in the 1996 fishery.

Estimates of harvest can be made from the 1994 and 1995 CWT ocean recoveries because an estimates of escapement of the 1992 and 1993 broodyear winter-run chinook were made in the river. Most, if not all, of the 1992 and 1993 broodyear hatchery reared winter-run chinook returned to Battle Creek instead of the main stem Sacramento River, having failed to imprint on the Sacramento River as juveniles (U.S. Fish and Wildlife Service 1996a).

The 1995 spawning escapement of hatchery-origin winter-run chinook was estimated at 88 U.S. Fish and Wildlife Service 1996a). The ratio of catch to catch plus escapement (C/C+E) for the 1992 broodyear is estimated at 0.54. The 1996 spawning escapement was estimated as 114 hatchery-origin adults (National Marine Fisheries Service 1997a). The ratio of C/C+E for the 1993 broodyear is estimated as 0.19. A weighted average harvest rate of 0.40 is obtained by pooling the ocean tag recoveries and estimated spawning returns for the 1993 and 1993 hatchery-origin broodyears. The new CWT data suggest that the present ocean harvest level of winter-run chinook is substantial.

In general, it should be noted that the calculation C/C+E tends to overestimate the actual harvest rate in the ocean, because it does not account for natural mortality in the ocean which is a poorly understood parameter. The C/C+E ratio is used to evaluate harvest of winter-run chinook in order to compare harvest levels with other stocks, such as fall-run chinook and Klamath fall chinook. Actual harvest rates cannot be calculated for Central Valley fall chinook salmon presently due to the lack of a comprehensive, basin-wide monitoring of adult escapement.

Additionally, the CWT data generally parallel results on the ocean distribution of ocean impacts from the fin-clip study. That is, CWT age 2+ winter-run chinook were recovered south of Point Arena throughout most of the recreational and commercial fishery seasons. The CWT data are not statistically sufficient to evaluate the distribution and timing of fishery impacts, but it appears that fewer fish were caught in October and November.

Genetic effects. Specific studies on the genetic effects of harvest on winter-run chinook have not been conducted. In general, however, fish populations experiencing sport or commercial harvest are genetically changed (Allendorf et al. 1987). Ricker (1981) found that the average size of chinook salmon caught in Pacific marine fisheries has decreased by more than 50% over the past 60 years and the average age at maturity by about 2 years. These changes may affect the genetic composition of a stock. Genetic changes can also occur because fishery regimes establish seasons that may skew harvest on certain segments of the stock, such as fish entering the river early or late (Nelson and Soule 1987).

Existing Protection Measures. NMFS is the federal government agency responsible for managing marine and anadromous fish from three to 200 miles offshore under the Magnuson Fishery Conservation and Management Act. The Magnuson Act created eight regional fishery councils, including the Pacific Fishery Management Council (PFMC), to advise NMFS on fisheries issues. Fisheries within 3 miles are under the jurisdictions of the states and treaty tribes and are designed to be consistent with PFMC management plans. The PFMC develops the Ocean Salmon Fishery Management Plan (FMP) which is approved, implemented and enforced by the Secretary of Commerce acting through NMFS. The PFMC also submits its recommendations for fishery regimes to the Secretary of Commerce.

The salmon FMP includes, as management objectives, the NMFS jeopardy standards or the objectives of NMFS recovery plans for salmon species that are listed as threatened or endangered under the ESA. CDFG also conducts evaluations on fisheries impacts to winter-run chinook pursuant to the California Endangered Species Act (CESA), but on recreational fisheries only since commercial fisheries are exempt from CESA. The PFMC's proposed plans and regulations for each season are reviewed, and an assessment of impacts is prepared for those salmon stocks listed as endangered or threatened under the ESA.

Following the listing of winter-run chinook under the Federal ESA, NMFS initiated consultation internally regarding the impacts of the Fishery Management Plan implementation for the commercial and recreational salmon fisheries on winter-run chinook. A biological opinion was issued in 1991, in which restrictions were imposed on the recreational fisheries south of Point Arena (where the majority of impacts on winter-run chinook seem to occur) (National Marine Fisheries Service 1991c). Beginning March 1, 1990, a conservation zone outside the Golden Gate was established from November 1 through April 30 to protect winter-run chinook returning to the Sacramento River (closure took effect on March 1, 1990). Also in 1991, the recreational season south of Point Arena, which traditionally ran from about February 15 through November 15, was shortened by 4 weeks, with 2 weeks removed from each end of the traditional season.

To limit harvest of winter-run chinook, NMFS also required that ocean harvest of Central Valley chinook not exceed harvest levels in 1990. Harvest on Central Valley chinook is estimated using an abundance index, called the Central Valley Index (CVI). The CVI harvest rate is the ratio of salmon harvested south of Point Arena (where 85% of Central Valley chinook are caught) to the CVI escapement. Since 1970, the CVI harvest rate has generally ranged between 0.50 and 0.80. In 1990 when harvest restrictions to protect winter-run chinook were first imposed, the CVI harvest rate was near the highest level at 0.79. In subsequent years, the CVI has been below this level: 0.71 in 1991, 0.71 in 1992, 0.72 in 1993, 0.74 in 1994, 0.78 in 1995 and 0.64 in 1996.

In 1996, the various restrictions under the 1991 Biological Opinion were reevaluated because of new information obtained from coded-wire tag (CWT) recoveries of hatchery winter-run chinook. Also, the reclassification of winter-run chinook from threatened to endangered provided a basis for reinitiating consultation. NMFS issued a biological opinions in 1996 and 1997 which concluded that incidental ocean harvest of winter-run chinook represented a significant source of mortality to the endangered population, even though ocean harvest was not a key factor leading to the decline of the population (National Marine Fisheries Service 1996a and 1997b). The 1996 opinion further concluded that mortality originating from incidental harvest as well as the continued implementation of the ocean salmon Fisheries Management Plan was likely to jeopardize the continued existence of winter-run chinook salmon.

As a result, NMFS in the 1997 opinion required that ocean harvest impacts be reduced to the extent needed to increase escapement of winter-run chinook by 31%. The process for identifying measures to achieve these harvest reductions involves both the PFMC and NMFS. As discussed above, the PFMC identifies measures to achieve any requirements under the ESA or FMP, and then proposes these measures to NMFS. NMFS then evaluates these measures for their adequacy and formally adopts them as appropriate. During 1996 and 1997, the PFMC proposed season/area closures and size limitations primarily in the ocean recreational fishery to achieve the NMFS jeopardy standard for winter-run chinook.

Other Ocean Fisheries

California salmon are also affected to a much lesser degree, as incidental catch in the following fisheries: bottom trawl for groundfish, mid-water trawl for Pacific whiting (*Merluccius productus*), and in the high seas driftnet fisheries.

Effects on Winter-run Chinook.

Bycatch of winter-run chinook, specifically, is considered negligible in these ocean fisheries. For the Pacific whiting mid-water trawl fishery, it was estimated that the bycatch of winter-run chinook was less than one fish (National Marine Fisheries Service 1991d). This represented an impact rate of less than 0.25% to the winter-run chinook ocean population. The bycatch of salmon in the bottom trawl fishery is estimated as comparable to that of the mid-water trawl (whiting) fishery (Erickson and Pikitch 1994). If all bottom trawl fishing in California was conducted in the Monterey area, where winter-run chinook abundance is greatest, the bycatch of winter-run chinook would still be expected to be less than one fish (National Marine Fisheries Service 1992). Other coastal commercial fisheries (shrimp trawl, pot gear, hook-and-line, and setnet) are believed to have virtually no salmon bycatch (National Marine Fisheries Service 1992).

In the late 1980s there was considerable concern over incidental and intentional catch of salmon by high-seas driftnet fisheries ostensibly directed at squid in the north Pacific. Driftnet fishing for squid was introduced by Japan in the 1970s. This fishery was highly profitable, and Korea and Taiwan also entered the fishery. High-seas driftnet fishing was banned by the United

Nations in 1992 although an illegal fishery of unknown magnitude continues to operate (Wayne C. Lewis, NMFS, Office of Enforcement, Northwest Area, pers. comm.). In illegal driftnet catches of salmonids that have been seized, a very small percentage of the fish have been chinook salmon (Pella et al. 1993). The impact of high-seas driftnet fisheries is probably negligible on winter-run chinook because chinook tend to remain deeper in the water column than other salmonid species. Also, chinook salmon from California are believed to remain primarily off the California coast rather than migrating on the high seas (Healey 1991).

Existing Protective Measures

In 1992, night fishing and at-sea processing were prohibited in the whiting fishery south of 42°N latitude. These restrictions, aimed at reducing bycatch of Klamath basin fall-run chinook and rockfish (*Sebastes* spp.) in central California also likely reduced the bycatch rate of winter-run chinook (National Marine Fisheries Service 1992).

In-River Sport Salmon Fishery

Historically, in California, almost half of the river sportfishing effort was in the Sacramento-San Joaquin River system, particularly upstream from the city of Sacramento (Emmett et al. 1991). In the Sacramento River, an estimated 8.7% of winter-run chinook escapement was harvested by recreational anglers from 1983 through 1986. In 1987, a quota of 175 fish was imposed on recreational harvest of winter-run chinook. A rolling closure was also enacted between Knights Landing and Redding, designed to protect winter-run chinook while allowing access to most other runs by anglers. These restrictions reduced the estimated harvest to: 1.3% of escapement in 1987, 4.2% in 1988, and 3.1% in 1989. Effective March 1, 1990, regulations were adopted by the Fish and Game Commission that prohibited the retention of salmon in the Sacramento River when adult winter-run chinook are present. These closures have virtually eliminated impacts on winter-run chinook by recreational angling in freshwater.

V. IMPACTS ON WINTER-RUN CHINOOK FROM FISH AND WILDLIFE MANAGEMENT PROGRAMS

Striped Bass Management Program

Striped bass are native to streams and bays of the Atlantic coast and the Gulf of Mexico. They were introduced to the Sacramento-San Joaquin estuary in 1879 and 1882, and expanded rapidly supporting a commercial fishery of over 1.2 million pounds by 1899 (Skinner 1962). Striped bass harvest was high up through the early 1960s, with catches averaging 680,000 fish, but by the late 1970s, the fishery decreased to an average catch of 200,000 fish (Table III-9). Catches continued to decline down to an average of about 150,000 fish during the 1980s, and most recent estimates indicate an average catch of 83,000 for 1990-1993. Illegal fishing is also prevalent and may kill thousands of juvenile striped bass, possibly equivalent to at least 125,000 legal-sized bass each year (Brown 1987).

Monitoring of the adult population similarly indicates a population decline over the past several decades. During the early 1970s, the average number of adults (age 3 and older) was estimated at about 2.2 million adults, but by the late 1970s, the population dropped to an average of about 1.7 million adults. Adult numbers continued to fall in the 1980s to an average 1.3 million adults, and then dropped again during the 1990s to an average 996,500 (1990-1993).

The CDFG conducts the Striped Bass Management Program, with the goals of stabilizing and restoring the striped bass fishery, and restoring and improving habitat for striped bass and other aquatic species in the Bay-Delta ecosystem (California Department of Fish and Game 1995). Specifically, CDFG's long-term goal is to stabilize and restore the striped bass population to 2.5 to 3 million adults. CDFG’s interim abundance goal, which was adopted by the California Fish and Game Commission, is to restore the striped bass population to the 1980 population level of 1.1 million adults within the next 5-10 years. However, the Fish and Game Commission also recognizes that actions to increase striped bass must be “consistent with the Department’s long-term mission and public trust responsibilities including those related to threatened and endangered species and other species of special concern” (California Fish and Game Commission 1996).

Table III-9. Estimated Abundance and Catch of Adult Striped Bass, and Percent Contribution of Hatchery Releases to Adult Population.

Year	Total Number of Adults (Age 3+)	Number of Legal-Sized Adults	Catch	Number Yearlings Stocked	Percent Hatchery Contribution
1969	2,187,750	1,646,000	282,000		
1970	2,381,943	1,727,000	209,000		
1971	2,029,002	1,600,000	274,000		
1972	2,507,889	1,883,000	320,000		
1973	2,008,419	1,637,000	274,000		
1974	1,947,893	1,477,000	338,000		
1975	2,316,615	1,850,000	444,000		
1976	2,099,913	1,581,000	329,000		
1977	1,191,321	924,000	157,000		
1978	1,758,429	1,152,000	188,000		
1979	1,620,385	1,156,000	179,000		
1980	1,305,847	1,116,000	137,000		
1981	1,177,258	911,000	100,000	62,640	
1982	1,235,918	825,000	131,000	90,548	
1983	1,291,980	1,010,000	239,000	101,351	
1984	1,487,806	1,048,000	234,000	165,005	
1985	1,254,520	1,038,000	206,000	513,029	1
1986	1,339,596	1,064,000	173,000	1,344,736	3
1987	1,371,155	1,038,000	158,000	971,298	4
1988	1,183,794	967,000	129,000	1,133,113	7
1989	1,028,163	873,000	76,000	1,425,357	11
1990	830,742	663,000	84,000	2,304,992	13
1991	1,058,533	828,837	110,000	2,878,122	13
1992	1,040,775	816,000	64,000	0	21
1993	776,333	700,000	90,000	28,000	26
1994	1,192,247	765,000	*	37,000	9
1995	*	*	*	100,000	*
1996	*	*	*	20,000 plus	*
				80,000 two-year olds	*
1997	*	*	*	113,000	*

*not yet determined.

At present, there are two elements of the CDFG's Striped Bass Management Program which may adversely affect winter-run chinook salmon: 1) the stocking of net-pen reared striped bass, and 2) sampling activities associated with the striped bass monitoring program.

Striped Bass Stocking

Because of the declining striped bass populations, CDFG began a large-scale program of stocking hatchery-produced striped bass in 1981. Releases increased from about 60,000 yearlings in 1981 to a peak of 2.8 million in 1991, and totaled to over 10 million juvenile striped bass (California Department of Fish and Game 1995). Concurrently, the hatchery contribution to the total adult striped bass population increased from less than 1 percent in 1984 to more than 30 percent in 1993. The greater contribution to the wild population has been attributed to the increased annual hatchery production and the declining population of wild fish.

The release of hatchery-produced juvenile striped bass was discontinued after 1991 to help protect winter-run chinook from striped bass predation (CDFG News Release, May 19, 1992). CDFG subsequently began an experimental program to rear striped bass, salvaged from the State and Federal pumping facilities, for one year in net-pens (in Suisun Marsh sloughs) to improve their survival, and then release the yearlings back to the Bay-Delta.

Effects on Winter-run Chinook. The primary concern with augmenting the striped bass population is the potential to increase predation on juvenile winter-run chinook. The extent of striped bass predation has not been empirically determined for winter-run chinook or any other chinook run in the Central Valley, and consequently, it is difficult to quantify. The only available information on striped bass predation are from several food habits studies conducted in the late 1950s and 1960s (Stevens 1966 and Thomas 1967), and several studies of predation at artificial structures (see Predation Section in this Chapter).

Steven's (1966) studies in the Delta generally found chinook salmon in small amounts in the striped bass diet (1% or less), but found somewhat greater quantities in sub-adult bass during the spring (4% by frequency occurrence) and adult bass in the spring (6% frequency of occurrence) and summer (5% frequency of occurrence). Thomas (1967) studied striped bass in the Sacramento River, Delta, and San Pablo and San Francisco bays and found more substantial amounts of chinook salmon in the striped bass diet, during time periods and locations when winter-run chinook occur. During the spring, chinook salmon comprised the majority (62% frequency of occurrence) of the bass diet in the middle Sacramento River; 22% in the lower Sacramento River; and 3% in Suisun Bay/Carquinez Strait area. During the fall, chinook were found in lesser amounts (3% in the middle Sacramento River only), and were not found in bass diet during the winter, although sample sizes were very small in the Sacramento River.

From these studies and information on the distribution, abundance and bioenergetics of striped bass and winter-run chinook, CDFG and NMFS have estimated that the percent of the winter-run chinook outmigrant population preyed upon by the current striped bass population is about 6%. This estimate, however, is highly uncertain because of the lack of specific data particularly regarding predation levels in the winter. Sampling in previous studies was limited in the winter, and in fact, there was no monitoring in the upper Sacramento River. Further studies are clearly needed to improve the understanding of predation impacts. This predation rate may also be an underestimate because it was based on striped bass consumption data in open water areas only (Thomas 1967 and Stevens 1966), and did not factor in the more intense predation that occurs at diversions and other physical structures (see Predation Section in this Chapter) (National Marine Fisheries Service 1995b). For example, mortality attributed to striped bass predation at Clifton Court Forebay has been estimated to range between 63% and 99% of those fish entering the Forebay. Also, due to a lack of information, the 6% estimate accounts for predation in the Delta and middle and lower Sacramento River only, and does not include predation that likely occurs in the upper Sacramento River, San Francisco Bay and the ocean.

The aquatic habitat of the Central Valley has changed profoundly over the last several decades such that the environment that the two species previously shared no longer provides as great a variety of microhabitats. With this altered ecosystem, there is more uncertainty that the striped bass population would have minimal impacts on the recovery of winter-run chinook. When both populations were at high levels in the late 1960s and early 1970s, striped bass populations were two orders of magnitude greater in abundance than winter-run chinook. Since winter-run chinook was listed, the striped bass population has also declined, but it is now nearly three orders of magnitude greater in abundance than winter-run chinook. The consequences of this relative disparity is unknown, but there is clearly a need to better understand the predator-prey dynamics of these two species.

Recently, a stochastic life cycle model of winter-run chinook has been developed which can examine how incremental increases in smolt mortality affects winter-run chinook population dynamics. This model estimated that the winter-run chinook population currently has a high probability of extinction, and that stocking striped bass (to achieve 1.1 million legal-sized adults in 10 years) would further raise the probability of extinction. Allowing such higher risks to winter-run chinook is not acceptable at this time. Winter-run chinook need to achieve higher abundances on a sustained basis before increasing the striped bass population. As winter-run chinook recover, the population should become more resilient to extinction over the short term. When winter-run chinook have demonstrated sufficient recovery, a more extensive striped bass stocking program may be considered with minimal risks to the continued survival and the recovery of winter-run chinook.

Striped Bass Monitoring Program

As part of the Striped Bass Management Program, monitoring of striped bass has been conducted, including the capture of adult bass with gillnets and fyke traps for tagging in the spring. (annually since 1967, except 1974 and 1979) (California Department of Fish and Game 1995).

Effects on Winter-run Chinook. Review of 1994 fyke trap data indicates that at least 5 adult winter-run chinook may have been captured, using spawning coloration as identification.[2] All of these fish were reported to be released in good condition. Two additional chinook salmon were killed in the fyke traps during the adult winter-run chinook migration period, but these fish could not be identified to run because their color had faded at death. Review of gillnet data indicates that 2 adult winter-run chinook may have been captured in 1994; one was released in good condition and the other was reported to be in sluggish condition. In total, the monitoring program may have captured 7 adult winter-run chinook in 1994, or approximately 4% of the 1994 year class. If the two mortalities from the fyke traps are included, as many as 9 adults or 5% of the 1994 year class may have been captured, with 1% killed. This represents a considerable proportion of the run, and at a critical point in the salmon's life history when the adults are close to reproducing.

DFG next conducted adult striped bass monitoring in 1996. Review of incidental catch data suggests that a minimum of two adult winter-run chinook were caught in fyke traps and gillnets, and potentially up to five, all of which were released in a healthy condition. Hence, a minimum of 0.2% of the 1996 year class may have been incidentally captured and a maximum of 0.5%.

Existing Protective Measures. In 1993, NMFS requested that CDFG obtain a Section 10 permit under the ESA prior to continuation of its striped bass stocking program. CDFG initiated efforts to obtain a Section 10 permit, and concurrently, began raising juvenile striped bass in net pens. Approximately 28,000 and 37,000 yearling bass were released into the Bay-Delta ecosystem in 1993 and 1994, respectively, which NMFS through informal consultation concluded would have minimal impacts.

CDFG planned more substantial releases for June of 1995 and 1996, but did not obtain a Section 10 permit in time for their scheduled releases. CDFG subsequently requested that the USBR act as a Federal nexus to conduct a Section 7 consultation for a one-year period (June 1995-June 1996). Accordingly, consultation between the USBR and NMFS (and USFWS) has resulted in restrictions on the stocking program, which include limiting the release of striped bass to 100,000 yearlings in 1995 and 1996, unless the winter-run chinook population demonstrates substantial recovery. CDFG also is working toward obtaining a Section 10 permit for future Striped Bass Management Program activities.

State and Federal Salmon and Steelhead Hatchery Programs

Five hatcheries currently produce chinook salmon in the Central Valley, with the three largest hatcheries (Coleman, Feather River, and Nimbus) in the Sacramento River Basin

[2] It is difficult to distinguish between adult winter-run chinook and spring-run chinook during much of their upstream migration.

(Table III-10). Most of these salmon hatcheries were constructed between 1940 and 1970 as mitigation for specific dams and water projects, and are funded by mitigation agreements with state, federal and public agencies and monies collected from commercial salmon fisherman.

Prior to 1967, only Nimbus and Coleman hatcheries had substantial production, but between 1967 and 1991, total Central Valley salmon production nearly doubled. At present, Central Valley hatcheries annually produce an average of nearly 33 million juvenile fall-run chinook, over 1 million juvenile spring-run chinook, about 0.6 million juvenile late-fall-run chinook, and over 2.5 million juvenile steelhead. This compares to an average annual production of about 40 million juvenile chinook, and 6 million juvenile steelhead for the entire state.

Effects on Winter-run Chinook

There are concerns that the release of large numbers of hatchery fish can pose a threat to wild winter-run chinook. Potential consequences to wild fish include hybridization and introgression, competition for food and other resources, predation, and increasing fishing pressure on wild stocks due to high hatchery production (Waples 1991b).

At present there is little evidence with which to evaluate past and current genetic impacts of Central Valley salmonid hatchery programs on the winter-run chinook population. Bartley and Gall (1990), using the technique of protein electrophoresis, found that populations of chinook from Central Valley hatcheries were genetically similar to wild populations and speculated that the release of hatchery fish in the Delta may have resulted in abnormally high straying and gene flow to native stocks. However, the great genetic similarity among all Central Valley chinook populations, as measured by protein electrophoresis, limits the statistical power of detecting genetic impacts from hatchery releases. An alternative hypothesis that cannot be falsified with present data is that Central Valley hatchery stocks have diverged little from their wild ancestors, in which case, the near-term genetic impacts of hatchery programs might be minimal. DNA studies may shed light on this problem in the future (Nielsen et al. 1994).

The general literature on the genetic impacts of artificial propagation programs on Pacific salmonids suggests that Central Valley hatcheries could have serious, direct and indirect, negative effects on the winter-run chinook. Straying of hatchery fish, for example, is a major cause of hybridization between hatchery and wild fish (Waples 1991b). Although straying, primarily among neighboring streams, is a natural phenomenon, hatchery fish have been documented to stray at a higher rate and farther than wild fish (see references in Waples 1991b).

Table III-10. List of Central Valley Salmon and Steelhead Production Hatcheries and the Average Annual Production of Chinook Salmon and Steelhead.

		Average annual production				
		chinook salmon stock				steelhead
Facility[3] and Period of Record	Location	fall	spring	late-fall	winter	
Feather River Hatchery (1968-1993)	Feather River	7,434,000	1,219,000[4]	N.P.[5]	N.P.	751,000
Nimbus Hatchery (1965-1993)	American River	8,810,000	N.P.	N.P.	N.P.	767,000
Mokelumne River Hatchery (1965-1993)	Mokelumne River	946,000	N.P.	N.P.	N.P.	161,000
Merced River Hatchery (1970-1993)	Merced River	579,000	N.P.	N.P.	N.P.	N.P.
Coleman National Fish Hatchery (1940-1993)	Battle Creek[6]	14,941,000	N.P.	639,000	26,000	814,000
Sum of average statewide production		32,710,000	1,219,000	639,000	26,000	2,493,000

In the Central Valley, two hatchery practices in particular might contribute to elevated straying levels: trucking of fingerlings to distant sites, and transfers between hatcheries. However, there is no evidence that these practices have affected winter-run chinook salmon. None of the spawned out carcasses recovered from the Sacramento River in 1994 and 1995 (a total of 129) or the tagged adults in

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3 All facilities are operated by the California Department of Fish and Game, except that Coleman National Fish Hatchery is operated by the U.S. Fish and Wildlife Service.

4 Spring-run chinook propagated at Feather River Hatchery are believed to have interbreed with fall-run chinook.

5 N.P. = not produced.

6 Battle Creek is a tributary of the Sacramento River.

these years (total of almost 400) were marked hatchery fish (U.S. Fish and Wildlife Service 1996). Genetic analysis of broodstock and carcasses likewise support the genetic distinctiveness of winter-run chinook salmon (D. Hedgecock pers. comm.).

Competition. Chinook salmon and steelhead artificially produced at and released from hatcheries may compete with (or displace) wild winter-run chinook for food or habitat in the river, estuary, and open ocean. The major source of competition from hatchery salmonids in the upper Sacramento River would be from releases by the Coleman National Fish Hatchery on Battle Creek. To reduce such interactions, the hatchery has discontinued releases of hatchery fish between July and October, when winter-run chinook are emerging and starting to rear as fry. This release schedule should allow wild juvenile winter-run chinook to become well established in the upper Sacramento River before encountering Coleman hatchery-produced juveniles.

The extent of competition between winter-run chinook and releases from other hatcheries is unknown but is expected to be low. Winter-run chinook generally outmigrate in peak numbers during different time periods than the other salmon and steelhead runs in the Sacramento River. In particular, fall-run chinook represent the majority of Central Valley hatchery production, and they are typically released in the spring after most juvenile winter-run chinook have migrated downstream to the Delta. Juvenile winter-run chinook are also generally larger than juvenile fall-run chinook, which may give them some competitive advantage. The size differences may also result in segregation according to size-dependent habitat preferences, as juvenile chinook salmon and steelhead move to faster and deeper waters as they grow (Everest and Chapman 1972). Also, runs are generally at levels well below those supported in the recent past such that the current population of salmonids may be below the current carrying capacity of the Sacramento River. This would tend to reduce competition among hatchery runs and wild winter-run chinook (U.S. Fish and Wildlife Service 1993d).

Competition among hatchery runs and wild salmon in the ocean is likely limited in most years. The ocean environment has been assumed to be nonlimiting because historical wild salmon abundances were much higher than the combined abundances of wild and hatchery salmon at present (Chapman 1986; Bledsoe et al. 1989), and standing stocks and production rates of prey resources were estimated to far exceed the food requirements of the present ocean populations (LeBrasseur 1972; Sanger 1972). A number of studies have found evidence that ocean conditions may limit salmon production and that a substantial percent of the total natural mortality may occur during early marine life (Parker 1968; Mathews and Buckley 1976; Bax 1983; Furnell and Brett 1986; Fisher and Pearcy 1988). However, in many populations much of this mortality appears to occur in the first month at sea; regardless of the number of smolts released. Brodeur et al. (1992) suggested that local depletion of resources could occur, especially of fish prey in a warm year of reduced productivity such as 1983 when prey were smaller and competitors such as mackerel were abundant. But in general, juvenile salmon do not appear to be food-limited in coastal waters during most normal years (Brodeur et al. 1992; Peterson et al. 1982; Walters et al. 1978).

Predation. The extent of predation by hatchery salmonids on winter-run chinook is also not known. Steelhead releases, primarily by the Coleman National Fish Hatchery, may have the greatest potential for inducing predation on winter-run chinook. Coleman National Fish Hatchery has a capacity to raise about 1 million yearling steelhead. Present production targets a release of about 600,000 in January and February at 125-275 mm (4 fish/pound) in length. The larger steelhead individuals do have the potential to prey on the smaller juvenile winter-run chinook (54-150 mm) in the population. Predation by steelhead from Coleman is thought to be relatively low because the hatchery steelhead: 1) tend to outmigrate rapidly, 2) during a period when in-river foraging conditions are suboptimal (i.e. high turbidity, low water temperature), and 3) during a time when there is an abundance of smaller prey such as newly emerged fall-run chinook salmon fry.

Predation by residualized[7] hatchery-released steelhead, however, could be substantial. The extent of residualization of hatchery steelhead trout smolts is presently unknown. With a potential annual release of over 1 million steelhead trout per year at Coleman National Fish Hatchery, even a small rate of residualization could result in a substantial predator population. The potential for residualized steelhead predation to impact winter-run chinook survival does warrant further study. The wild trout population in the Redding-Anderson area of the Sacramento River is estimated to be quite large, at about 6,000 fish per mile (Mike Berry, CDFG, pers. comm.). A complete impact analysis of residualized steelhead becomes complicated because of the difficulty in distinguishing between wild and hatchery trout. A marking program for all hatchery steelhead would assist in this analysis.

Predation from steelhead released by Feather River Hatchery and Nimbus Fish Hatchery has not been evaluated but may also be important. Each of these hatcheries has a capacity to raise about 400,000 yearling steelhead to a size of 3-4 fish/pound. Feather River Hatchery fish are planted in the Feather River below Yuba City, most by the end of March, and the Nimbus Fish Hatchery fish are mainly trucked and released in the Carquinez Strait between January and April (California Department of Fish and Game 1990). Feather River hatchery steelhead are released at a large enough size and at a time when they could intercept winter-run chinook. Nimbus Hatchery steelhead would also be large enough to prey on winter-run chinook salmon in the Bay and ocean.

Predation by other hatchery salmonids should be minimal in the upper Sacramento River. Fall-run chinook are released from Coleman hatchery at smaller sizes than winter-run chinook, and are more likely be prey than predators on winter-run chinook. Predation by late-fall chinook is probably also limited. Predators rarely select prey items exceeding 1/3 their length such that

[7]Residual steelhead are those that have an anadromous lineage but are themselves nonanadromous; the term was first proposed by Ricker (1938) in describing life history variations in *Oncorhynchus nerka*. The change in life history may be the result of a physical or physiological barrier to migration (e.g. a dam, or too rapid or slow growth that precludes smoltification).

only the largest hatchery late-fall run chinook would be capable of preying on the smallest wild winter-run chinook (U.S. Fish and Wildlife Service 1993d). Late-fall chinook also emigrate rapidly, during the late fall and early winter when foraging conditions are suboptimal. This should further reduce the potential for predation by late-fall run chinook.

Ocean Fishery. Increased production and survival of hatchery chinook salmon has resulted in increasing contributions of hatchery fish to adult spawning escapements since 1967. When hatcheries are successful at producing adult fish, the potential harvest rate may become very high (Hilborn 1992). Fewer adults are needed to maintain a hatchery run because of high survival from eggs to smolts under hatchery conditions, such that high percentages of returning hatchery fish can be harvested while still sustaining the hatchery run. As harvest rates are raised to match the potential productivity of hatchery stocks, wild stocks may become overfished.

Current harvest rates of Central Valley chinook salmon stocks are high enough to adversely affect the natural production in some rivers, and to adversely affect winter-run chinook. Accurate quantification of the Central Valley hatchery contribution to ocean chinook salmon landing have not been developed because of the lack of a consistent hatchery marking program in the Central Valley. Nonetheless, Dettman and Kelley (1987) estimated that for the years 1978-1984, an average of 11.03% of ocean catches off California were composed of Feather River hatchery fish, and an average of 13.1% were American River hatchery fish. Annual contributions of hatchery fish to escapement in recent years have been estimated as: 1) 26% (averaged for 1975-1987; Cramer 1990) and 78% (average 1975-1984; Dettman and Kelley 1987) for the Feather River; 2) 29% (average 1975-1987; Cramer 1990) and 86.6% (average 1975-1984; Dettman and Kelley 1987) for the American River; 3) 40% for the middle Sacramento River (average 1975-1987, Cramer 1990); and 4) 41% for the upper Sacramento River (average 1975-1988, Cramer 1990).

Existing Protective Measures

The USFWS has consulted with the NMFS under Section 7 of the ESA for their operations of the Coleman National Fish Hatchery. This consultation resulted in a ceiling being placed on hatchery production, and the initiation of investigations to evaluate impacts of hatchery-produced salmonids on wild winter-run chinook. NMFS has requested that the CDFG obtain a section 10 incidental take permit for operation of state hatcheries that may affect winter-run chinook (National Marine Fisheries Service 1993c; National Marine Fisheries Service 1996b), but the State has not yet initiated efforts to obtain this permit.

Rice Stubble Decomposition and Waterfowl Habitat Development (Riceland Habitat Joint Venture)

Agricultural practices require the elimination of rice stubble because it serves as a source of disease to rice crops in the following year. Historically, this has been done by controlled burning of fields. In 1991, the Air Resources Board implemented the Agricultural Burning Reduction Act, which required the phasing out of agricultural burning in the Central Valley over a 10-year period. A variety of alternative practices are being evaluated to eliminate rice stubble through natural decomposition for the over 500,000 acres of rice planted in the Central Valley (in 1994). One of these measure is to flood harvested rice fields to a depth of 12 inches or more shortly after harvest, and to allow the stubble to decompose during November through February. Additional measures being evaluated include flooding at shallower depth, flooding and drying, and rolling the rice stubble.

The timing and magnitude of Sacramento River water diversions for rice stubble decomposition may be a significant problem for winter-run chinook since the diversions would occur at a time when juvenile winter-run chinook are present in the Sacramento River above Sacramento. Juveniles present during the new diversion period (primarily in October or November, but potentially extending into the spring) would be vulnerable to entrainment at unscreened or improperly screened diversions.

Is anticipated that by the year 2000, assuming annual production of 450,000 acres of rice, that 112,500 acres of rice stubble will be burned (25%), 50,000 acres will be diverted for purposes of alternative technologies (11%), and 287,500 acres would be subject to a riceland decomposition program (64%). About one-half of the latter quantity (142,825 acres) would be flooded each fall for rice stubble decomposition. This anticipated need coincides with ongoing and expanding programs to flood private duck clubs, enhance natural wetland, and flood State and Federal wildlife refuges and wildlife areas in the Sacramento Valley; all of which begin flood up operations in the fall.

All totaled, the fall flood up programs for waterfowl and rice stubble decomposition will require about 425,000 acre-feet (AF) of water annually: 142,825 AF for rice decomposition, 102,750 AF for private duck clubs, and 179,000 AF for State and Federal refuges. Additional concerns include that the conveyance losses associated with these programs could equal the amount of water delivered, and that over 600,000 acres of land are annually available for the production of rice. Rice stubble decomposition water will also be released in late winter and early spring. The quantity and quality of this water is unknown at this time, but it has the potential to be low in dissolved oxygen, high in organic and inorganic compounds, high in herbicides and pesticides, and could be of a higher ambient water temperature than the Sacramento River.

VI. OTHER PROBLEMS IN THE CONSERVATION OF WINTER-RUN CHINOOK

Predation

Predation occurs throughout the river and ocean phases of winter-run chinook, but the magnitude and extent of predation have not been quantified. There are essentially three classes of predators on winter-run chinook: birds, fishes, and marine mammals. Avian predators on winter-run chinook include: 1) diving birds such as cormorants and gulls (Vogel et al. 1988), 2) terns and mergansers, 3) wading birds such as snowy egret, great blue heron, black-crowned night heron, and green heron, and 4) raptors such as osprey. Piscivorous predators include both introduced and native species. The most important introduced predator is striped bass (*Morone saxatilis*), but white catfish (*Ictalurus catus*), channel catfish (*Ictalurus punctatus*), and American shad (*Alosa sapidissima*) may also prey on juvenile chinook. Native predatory species include Sacramento squawfish (*Ptychocheilus grandis*), prickly sculpin (*Cottus asper*), and steelhead (*Oncorhynchus mykiss*).

Predation in the Sacramento River and Delta

Predation by native species is a natural phenomenon and should not have a serious effect in the free-flowing river. Winter-run chinook have co-evolved with its native predators and have developed strategies to avoid predation. However, predation by introduced species and increased predation due to artificial in-water structures may have resulted in gross imbalances in the predator-prey relationships and community structure in which winter-run chinook evolved.

Effects on Winter-run Chinook. Artificial structures, such as dams, bridges, diversions, create shadows and turbulence, which tend to attract predator species and to create an unnatural advantage for predators (Stevens 1961, Vogel et al. 1988, Decoto 1978). They may also provide little natural vegetative structure or cover, which normally provides a shelter for juvenile chinook from predators. Specific locations where predation is of concern include: RBDD; GCID Hamilton City Pumping Plant; flood bypasses; release sites for salmon salvaged at the State and Federal fish facilities; areas where rock revetment has replaced natural river bank vegetation; the Suisun Marsh Salinity Control Gates; and Clifton Court Forebay (CCF).

RBDD. Predation at RBDD on juvenile winter-run chinook is believed to be higher than normal due to factors such as water quality and flow dynamics associated with the operation of this structure. The most important predator at RBDD is squawfish (Garcia 1989). Squawfish migrate annually upstream and arrive at RBDD from March to June, but some squawfish are present year round at the dam. Striped bass have also been captured immediately below RBDD in limited but regular numbers and have been found to contain juvenile salmonids (USFWS unpublished data cited in Garcia 1989, Villa 1979). Striped bass schools were also observed by USFWS divers below RBDD in September 1982. In addition, Hall (1977) found that five American shad captured at RBDD in June 1976 contained two to seven juvenile salmon each.

Juvenile winter-run that migrate downstream soon after emerging from the gravel in summer and early fall will encounter RBDD when the gates are still down. They must cross Lake Red Bluff when turbidity is generally low and water temperatures are still relatively high. Due to their small size, these early emigrating winter-run juveniles may be very susceptible to predation in the lake by squawfish and cormorants (Vogel et al. 1988). In passing the dam, juveniles are subject to conditions which greatly disorient them, and make them highly susceptible to predation by fish or birds.

In the past when the RBDD gates were down at least from April through November, late-migrating juvenile winter-run chinook passing RBDD in early spring likely suffered the greatest losses since squawfish abundance was higher at this time of year and river conditions were generally favorable for predators, especially during dry years. The impacts of these losses were also more important due to the overall higher survival of these smolts (versus actively migrating fry) and their greater probability of contribution to the adult population.

Flood Bypasses. There are some concerns that predation is higher in flood bypasses. In one survey of the Sutter Bypass, the most abundant species captured included chinook salmon and Sacramento squawfish (Jones & Stokes 1993a). Surveys conducted in the Sutter Bypass during flood events in February through April 1993 found juvenile chinook salmon, including fish in the winter-run chinook size range. In April 1996, an estimated 10,860 juvenile spring and fall-sized chinook salmon were also captured during the seining of about 1 acre of the Sacramento Bypass (Jones & Stokes 1996). Predation by herons was considered high. Also, warm water temperatures and algal blooms were thought to increase salmon mortality by contributing to low dissolved oxygen levels and the coincident increased vulnerability to predation.

GCID Hamilton City Pumping Plant. In evaluations at GCID, Decoto (1978) suggested that predation could be an important factor contributing to losses of juvenile salmonids. In mark-recapture studies, 66% of the salmon were unaccounted for in bypass evaluations, and 82% were unaccounted for in culvert evaluations. More recent studies suggest that Sacramento squawfish is the primary predator at GCID (Cramer 1992), although striped bass were also found with chinook salmon in their stomachs (Steve Cramer, pers. comm. as cited in National Marine Fisheries Service 1995b).

Fish salvage release sites. Orsi (1967) evaluated predation at the Jersey Island release site for salvaged fish from the State and Federal Fish Facilities from mid-June through July in 1966 and 1967. Striped bass was the major predator at the release site, with black crappie and white catfish ranking second and third, respectively, and also, squawfish, largemouth bass, and bluegill. Orsi estimated that overall predation occurred on about 10% of the salvaged fish released per day during multiple releases (1 million fish/day), and over 80% of the predation was from striped bass. He qualified this estimate as potentially being high, and not applicable to other sites such as the Sacramento River. Similarly, Pickard (et al. 1982) conducted predation studies of salvage release sites from 1976 to 1978. Fish, salvaged from the State's Fish Facility, were regularly transported and released into the lower Sacramento River at Horseshoe Bend. More predator fish were collected at the release site than at the control site, with striped bass and Sacramento squawfish being the primary predators. Also, more fish remains were found in the predators' guts at the release site than at the control site.

Rock Revetment Sites. The USFWS conducted a study to assess the relationship of juvenile chinook salmon to the construction of rock revetment type bank protection between Chico Landing and Red Bluff (Michny and Hampton 1984). They found that piscivorous predators such as Sacramento squawfish and prickly sculpin were more abundant at riprapped sites than at naturally eroding bank sites with riparian vegetation (Michny and Hampton 1984). Conversely, juvenile salmon were found more frequently in areas adjacent to riparian bank habitat than at riprapped sites. Riparian habitat provides overhead and submerged cover, an important refuge for juvenile chinook from predators.

Clifton Court Forebay. Overall predation rates for salmon smolts in Clifton Court Forebay (CCF) have been estimated for those fish entering the forebay at: 1) 63% - 98% for fall-run chinook (California Department of Fish and Game 1993a); and 2) 77% - 99% for late-fall-run chinook (California Department of Fish and Game, unpublished data) (Table III-11). In mark-recapture studies, estimated mortality rate per mile in CCF was 91.3%, compared to 2.7% for the central Delta and 0.9% for the main stem Sacramento River (between Ryde and Chipps Island). This difference in mortality rates was thought to be due to the greater abundance of predators, primarily striped bass, in CCF, as well as hydraulic actions, and the operational and physical design of CCF. During high tide, striped bass density in CCF has been estimated to be 3 to 17.5 times more than the density of striped bass in the Delta. At low tide, striped bass density in CCF has been estimated as roughly 5 to 21 times more than in the Delta.

Table III-11. Summary of Clifton Court Forebay Pre-Screen Loss Studies on Hatchery Juvenile Chinook Salmon (California Department of Fish and Game 1994b).

Date	Salmon Run	Pre-screen loss rate (%)	Temperature (avg/day°F)	Pump Exports (avg. af/day)	Predator Abundance	Size at Entrainment (mm fl)
Oct 76	Fall	97.0	65.4	2,180	NA	114
Oct 78	Late-fall	87.7	57.5	4,351	NA	87
Apr 84	Fall	63.3	61.2	7,433	35,390	79
Apr 85	Fall	74.6	64.1	6,367	NA	44
Jun 92	Fall	98.7	71.7	4,760	162,281	77
Dec 92	Late-fall	77.2	45.4	8,146	156,667	121
Apr 93	Fall	94.0	62.0	6,368	223,808	66
Nov 93	Late-fall	99.2	53.7	7,917	NA	117

NA = estimates not available

Suisun Marsh Salinity Control Structure. CDFG conducted predation studies from 1987-1993 at the Salinity Control Structure to determine if the structure attracts and concentrates predators. The dominant predator species at the structure was striped bass, and juvenile chinook were identified in their stomach contents. Catch-per-unit-effort (CPUE) of bass has generally increased at the structure from 1987 (less than 0.5, pre-project) to 1992 (3.0, post-project), and declined somewhat in 1993 (1.5) (California Department of Fish and Game 1994c). In comparison, CPUE was 3.44 at Clifton Court Forebay and 1.65 at the south Delta barriers during the same period and using identical gear.

Existing Protective Measures. There have been only limited efforts to reduce predation problems. At the Red Bluff Diversion Dam, a squawfish derby was held in 1995 to reduce squawfish abundance. However, this sport fishery is unlikely to measurably alleviate predation from a migratory species. The fishery could temporarily reduce squawfish abundance, but more squawfish are likely to repopulate the area. Sacramento squawfish are also more abundant at RBDD during the spring, and a spring fishery could cause incidental catches of winter-run chinook. The preferred solution is to eliminate or reduce the feeding habitat that the RBDD creates by seasonally or permanently raising the gates. At the Glenn-Colusa Irrigation District, the river channel at the check dam has been modified to improve passage of juvenile salmonids into the bypass, which should help reduce predation. At Clifton Court Forebay, programs have been proposed to catch striped bass and transfer them back to the estuary (California Department of Fish and Game 1994b). However, striped bass are also a migratory species, and are likely to return to the forebay to continue foraging at high levels at this site.

Ocean Predation

Ocean predation very likely contributes to natural mortality in winter-run chinook, however, the level of predation is unknown. In general, chinook salmon are prey for pelagic fishes, birds, and marine mammals, including harbor seals, sea lions, and killer whales. There has been recent concerns that the rebounding of seal and sea lion populations, following their protection under the Marine Mammal Protection Act of 1972, has resulted in substantial mortality for salmonids. Predation rates on Central Valley chinook salmon have not been studied, but research has been conducted in other estuaries. At the mouth of the Russian River, Hanson (1993) found that maximum population counts of seals and sea lions corresponded with peak periods of salmonid returns to the hatchery upriver. However, Hanson (1993) concluded that predation was minimal on adult salmonids because: 1) only a few pinnipeds foraged in the area, 2) their foraging behavior was confined to a short portion of the salmonid migration, and 3) their capture rates were low. In the lower Klamath River, Hart (1987) reported predation rates of 3.6% and 7.9% of the tagged fish in 1981 and 1982, respectively, from harbor seals on chinook, coho and steelhead. It is important to note that marine mammal and chinook salmon populations evolved together and co-existed long before humans played a role in controlling either species.

Introduced species

Introduced species as a factor in the decline of winter-run chinook cannot be quantified. However, certain introduced species may inhibit the recovery of winter-run chinook due to predation and habitat interference.

Invertebrate Introductions

Numerous exotic invertebrate species have been introduced into the Delta and San Francisco Bay. These introductions have been attributed mainly to the discharge of ship ballast water. One of the most important invertebrate introductions has been the Asian clam, *Potamocorbula amurensis*, which was first detected in 1986 and has since dramatically increased in abundance and distribution. A planktonic filter-feeder, its introduction has coincided with very low phytoplankton blooms in the North Bay. The Asian clam can be found in extremely high densities ($\geq$ 10,000 individuals/m2), and is capable of filtering large quantities of water (Hollibaugh and Werner 1991). This disruption at the base of the food chain appears to have induced changes to higher trophic levels. Obrebski et. al. (1992) found that 12 out of 20 zooplankton species in the estuary have declined significantly in abundance between 1972 and 1988. Of the remaining species, seven have shown no trend in abundance, and one introduced species (*Oithona davisae*) has increased in abundance. With these changes in species composition and abundance of zooplankton, the availability of normal food items in the diet of juvenile chinook during emigration through Suisun, San Pablo, and San Francisco bays could be changed and potentially reduced.

Fish Introductions

Some fish introductions have occurred accidently, but most fish have been intentionally introduced for sport and commercial fishing, forage for game fish, bait, insect and weed control, aquaculture, and pets (Moyle 1976). By far, the most important fish introduction for winter-run chinook has been striped bass (discussed in Striped Bass Management Program section in this Chapter). Other introduced fish species, such as American shad, catfish species, killifishes, mosquitofish, and largemouth bass, consume insects which juvenile chinook salmon also feed upon. However, it is difficult to determine if there is direct competition for these same food resources. It is unlikely that there is direct competition for space or that there is habitat interference.

Existing Protective Measures. Regulatory measures to prevent introductions from ship ballast water discharge are limited in California. However, State of State Assembly Bill 3207 does require vessel operators carrying ballast water to submit a report to the CDFG, who in turn monitors the ships' compliance with the *Guidelines for Preventing the Introduction of Unwanted Aquatic Organisms and Pathogens from Ships' Ballast Water and Sediment Discharges* (adopted by the International Maritime Organization on July 4, 1991). Although this law allows for the development of important information, it does not provide for any regulatory or enforcement measures to prevent the introduction of non-indigenous species.

To prevent a zebra mussel invasion, the California Department of Food and Agriculture (CDFA) has listed the zebra mussel as a prohibited species and inspect trailered boats at State border inspection stations. The CDFA requests owners, whose boats have the zebra mussel attached, to clean their vessels and have them inspected before launching. An informal group of federal and state agencies (the Interagency Western Council) are also exploring the potential to prevent the spread of the zebra mussel across the continental divide.

Infectious Disease

Infectious disease is a normal component in the life history of both hatchery-reared and natural chinook salmon. Most pathogens endemic to Sacramento River chinook have evolved with their salmon hosts and are not recent introductions. Endemic pathogens which have caused serious health problems in Central Valley salmon hatcheries include Infectious Hematopoietic Necrosis Virus (IHNV), *Renibacterium salmoninarum, Yersinia ruckeri, Flexibacter columnaris, Ceratomyxa shasta*, *Ichthyophthirius multifiliis*, and *Nanophyetus salmincola* (Cox 1993). Numerous other bacterial, parasitic, and fungal species have also been identified as pathogenic to hatchery populations under appropriate conditions. It is assumed that epizootics occur less frequently in spatially-dispersed, natural populations, but typically, acute large-scale die-offs have to occur before they are observed.

Many fish in a population may be infected by a pathogen, but do not become seriously diseased unless exposed to poor environmental conditions. The environmental conditions which favor infectious agents vary with the specific pathogen. However, factors such as low oxygen, contaminants, high temperatures commonly produce a stress response in the host. This response allows for rapid multiplication of the pathogen.

Effects on Winter-run Chinook

There is only limited information available on infectious diseases in winter-run chinook. Most of this data has come from the USFWS's Winter-run Chinook Salmon Propagation Program at Coleman National Fish Hatchery.

Adult On a population level, the main effects of infectious disease in adult chinook are: 1) pre-spawn mortality, 2) reduced fecundity, and 3) transmission of pathogens to the progeny (vertical transmission). Pre-spawn mortality, due to fungal and bacterial infection, was a serious impediment to the Winter-run Chinook Salmon Propagation Program's success until the implementation of antibiotic and fungicide treatments in 1991 (U.S. Fish and Wildlife Service 1991). It can be assumed that winter-run adults in the Sacramento River face similar diseases. In particular, those adults which migrate and hold until spawning in warm water would be at increased risk from temperature-accelerated bacterial infections from Aeromonids and *Flexibacter columnaris* (Groberg et al. 1978, Amend 1970).

Winter-run chinook, like other Sacramento River chinook populations, also have a high incidence of IHNV infection (W. Wingfield, pers. comm.). In 1990-1992, the incidence of IHNV infection has ranged from 45% - 96% in adult winter-run chinook in the propagation program. Latent IHNV infections are commonly expressed in maturing salmon, but do not appear to affect their health (Mulcahy et al. 1984). However, vertical transmission of IHNV from the adult to the highly susceptible progeny can cause significant mortality (Wolf 1988).

Other pathogens detected in adult winter-run chinook in the propagation program have included the bacteria *Renibacterium salmoninarum* (agent of Bacterial Kidney Disease), and the intestinal parasite *Ceratomyxa shasta.* Also, an important new disease of captive winter-run chinook has been detected, which is caused by a systemic protist called the “rosette agent”. The rosette agent has also been found in late-fall chinook originating from the Coleman National Fish Hatchery, but has not yet been found in fall-run chinook (U.S. Fish and Wildlife Service 1996b). In 1995, FWS detected a high incidence of the rosette agent in adult late-fall run chinook originating from and returning to the Coleman hatchery. However, the rosette agent was not found in any of the unmarked late-fall chinook collected at the Keswick fish trap for spawning at Coleman hatchery. Therefore, it appears that the infectious stage of the rosette agent may be occurring only in the Battle Creek watershed (Scott Foott, pers. comm.). Evidence thus far suggests that the disease requires a minimum of eighteen months to manifest itself in juvenile chinook. Also, it appears that the parasite is detectable in coho as well as chinook salmon, but the susceptibility of rainbow, brook, and brown trout to the disease appears limited (Arkush and

Frasca 1996).

Juveniles Little is known of the pathogens and diseases which affect naturally produced juvenile chinook in the Sacramento River. IHNV has been detected in natural downstream migrants (W. Wingfield, pers. comm.). The broodyear 1991 winter-run juveniles being held for the captive broodstock program have had experienced disease problems due to infections from *R. salmoninarum*, *F. columnaris* (Columnaris disease), *Nanophyetus salmincola* (trematode), external fungus (in precocious males only), and the rosette agent. It should be assumed that naturally produced juvenile winter-run chinook face similar disease situations. In particular, the presence of IHNV and *R. salmoninarum* in captured adults indicates that these vertically-transmitted diseases may affect the health of juvenile winter-run chinook. Environmental stressors such as contaminants and high temperatures would likely act to immunosuppress juveniles and increase their risk of infectious disease.

Existing Protective Measures

CDFG has several protective measures in place to control the introduction of diseases into drainages. CDFG prohibits the importation of fish into California from areas that are known to have infected, diseased or parasitized fish and other organisms (Fish and Game Code Article 3, §2270). CDFG also requires that all interstate transfers are certified, and CDFG conducts border inspections to ensure compliance with disease regulations. Within the state, CDFG prohibits the transportation of infected, diseased, or parasitized fish between drainages (Fish and Game Code Article 4, §6305). In addition, CDFG requires that fish (and other plants and animals) be summarily destroyed if found to be infected, diseased or parasitized (Fish and Game Code Article 4, §6302).

CDFG and USFWS also use various protocols to control the infection of diseases within hatcheries, including using therapeutic, disinfectant and mechanical means, vaccinations, and management actions. Therapeutic treatments are used to control such bacteria infections as columnaris, and external protozoans such as trematodes. Disinfectants are used to prevent transmission of viral agents and fungus, especially for egg-borne diseases, such as *Ceratomyxa shasta*, BKD, and IHNV. Mechanical methods include sterilization of water using ultraviolet treatment and ozonation.

VII. IMPACTS FROM CLIMATIC VARIATION

Drought Conditions

Droughts are a natural phenomenon in the arid, Mediterranean climate of California. California droughts have been measured in terms of precipitation, runoff, and reservoir storage. During normal water years, 5 to 7 major storms precipitate 1 to 2 inches of rain each in the Sacramento Valley and corresponding equivalents of rain and snow in the Sierra (Roos 1992). When only 3 to 5 storms occur, California experiences a dry year. During the drought of 1977, precipitation was 45% of normal, whereas precipitation during the drought years of 1987-1994 averaged 77% of normal.

The Sacramento River Index (the sum of unimpaired runoff of the upper Sacramento, Feather, Yuba, and American rivers) provides another indicator of the severity of past droughts. During the most recent drought of 1987-92, the SRI averaged 10.0 million acre feet (MAF), or 54% of the average 18.4 MAF of runoff. This drought was unique in that each year runoff was similar, about half of average. In 1976-77 the SRI was 5.1 MAF, or 28% of average. Runoff during the historical 6-year drought from 1929-34 was 9.8 MAF, similar to the 1987-1994 drought. Prior to 1906, there are other indirect indicators of drought in the Sacramento River Basin, such as tree ring data. Tree ring widths are not perfectly correlated with actual measured droughts, however, they provide a reasonable indicator of historic drought periods. They are also useful in comparing the historic record with measured runoff or precipitation (Table III-12) (Roos 1992).

Effects on Winter-run Chinook.

The tree-ring data indicate that drought periods have occurred fairly regularly over at least the past four hundred years (Table III-12). Historically, these dry and critically dry years likely resulted in depressed year classes of winter-run chinook, yet evidently, the population was sufficiently resilient to survive the dry periods and rebound. The present environmental conditions of the Sacramento River and Bay-Delta, however, are far from its historic, natural state. The ecosystem is tremendously altered by the water-supply and distribution systems, habitat degradation, and many other factors. These anthropogenic changes hamper the ability of winter-run chinook to recover from the most recent drought occurrences. The management of the Sacramento River and Bay-Delta during the recent drought periods was a primary factor precipitating the endangered status of the winter-run chinook population. In the 1976-1977 drought, winter-run chinook dropped from an average of 26,155 to 1,760 three years later (1979-1980)[8]. In the subsequent drought, winter-run chinook declined from an average of 2,171 (1986

[8] Effects on winter-run chinook may have been compounded by poor ocean conditions that began in 1976. However, winter-run eggs are believed to have suffered substantial mortality in 1976 and 1977, due to warm water in

to 1988) to 388 three years later (1989 and 1991).

Table III-12. Sacramento River Multi-Year Droughts Reconstructed from Tree-Rings Prior to year 1900.

Period	Length (years)	Average Runoff (MAF)
1579-82	4	12.4
1593-95	3	9.3
1618-20	3	13.2
1651-55	5	12.3
1719-24	6	12.6
1735-37	3	12.2
1755-61	6	13.3
1776-78	3	12.1
1793-95	3	10.7
1839-41	3	12.9
1843-46	4	12.3
1918-20 (actual)	3	12.0
1929-34 (actual)	6	9.8
1959-62 (actual)	4	13.0
1987-92 (actual)	6	10.0

Ocean Conditions

Mechanisms linking atmospheric and oceanic physics and fish populations have been suggested for fish stocks in general (Shepherd et al. 1984) and for Pacific salmon specifically (Rogers 1984, Brodeur and Ware 1992, Francis et al. 1992, Francis 1992, Hare and Francis 1993, Ward 1993). Many studies have tried to correlate the production or marine survival of salmon with environmental factors (Pearcy 1992, Neeley 1994). Salmon survival has been found to be associated with ocean conditions such as sea surface temperature and salinity, especially during the first few months that salmonids are at sea (Vernon 1958, Holtby and Scrivener 1989, and Holtby et al. 1990). Relationships have also been found between salmon production and sea surface temperature (Francis and Sibley 1991, Rogers 1984, and Cooney et al. 1993) . Some studies have tried to link salmon production to oceanic and atmospheric climate change. For example, trends in Pacific salmon catches and winter atmospheric circulation have been found to be similar in the North Pacific (Beamish and Bouillon 1993 and Ward 1993).

the Upper Sacramento River. Also, the QWEST index and export/inflow ratios indicate poor, hydrologic conditions in the Delta during 1976 (see graphs in section on Adverse Flow Conditions: Delta Hydrodynamics).

Three biological production zones have been identified for fish assemblages in the North Pacific Ocean: the Central Subarctic Domain, Coastal Upwelling Domain, and the Coastal Downwelling Domain (Ware and McFarlane 1989). Intermediate to these domains is the North Pacific Transitional Region. The Central Subarctic Domain is located north of the Subarctic Current, east of 170°W and west of the continental shelf of North America and is dominated by sockeye (*Oncorhynchus nerka*), pink (*O.gorbuscha*), and chum (*O. keta*) salmon. The prominent circulation features in the Central Subarctic Domain include the Subarctic Current and the Alaskan Gyre. The Coastal Upwelling Domain is located on the continental shelf and extends from about 25°N to 50.5°N and is dominated by Pacific hake (*Merluccius productus*), Pacific Sardine (*Sardinops sagax*), northern anchovy (*Engraulis mordax*), and Pacific mackerel (*Scomber japonicus*). The large physical feature of this domain is the California Current. The Coastal Downwelling Domain extends along the North American continental shelf from 50.5°N up to the Aleutian Islands and is mainly inhabited by walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), Pacific halibut (H*ippoglossus stenolepis*), sablefish (*Anaploma fimbria*), Pacific herring (*Clupea harrengus*), chinook salmon (*O. tshawytscha*), and coho salmon (*O. kisutch*). The prominent physical feature here is the Alaska Current.

These three domains are described as being linked by the Subarctic Current and its northern (Alaska Current) and southern (California Current) branches. The most prominent feature of the North Pacific Transitional Region, and a structure which plays a role in the definition of the major physical and biological domains, is the Subarctic Front. Frontal dynamics influence forage aggregations and lead to higher biological productivity at the Subarctic Front which impacts species at higher trophic levels, such as salmonids (McGowan 1986). Variability in the Subarctic Front may affect physical features which influence production, both in the Central Subarctic Domain and downstream in the coastal domains (Reid 1962, Wickett 1967, Eber 1971, Favorite and McLain 1973, Colebrook 1977, Chelton et al. 1982, Fulton and LeBrasseur 1985, Ware and McFarlane 1989). Although the Subarctic Front can be analytically defined, its structure changes in both space (White 1982, Levine and White 1983) and time (White et al. 1980). It moves, intensifies, decays, and undergoes seasonal changes (Roden 1977).

The influence of Subarctic Front dynamics on salmonids is probably not a direct cause-effect relationship, but rather, influences salmonids as part of trophic interactions (Pearcy 1992). The interaction or control might be "top-down" by predators, or "bottom-up" through lower trophic levels. For example, responses of predators to coho salmon smolt availability, and that of alternative prey species such as Pacific herring, could influence survival rates, with years of high upwelling dispersing the smolts and providing more alternative prey (Pearcy 1992). Several studies have examined the possibility that salmonid production or survival is related to food availability. Salmon abundance has been linked with coastal chlorophyll concentrations, primary production, and upwelling (Pearcy and Fisher 1988). Studies of other pelagic organisms have also indicated the potential importance of oceanic conditions to salmonid production. This is especially true for organism which may directly affect salmonids through trophic interactions including phytoplankton, zooplankton, cephalopods, and some fish upon which salmonids prey

(Pearcy et al. 1985), as well as marine mammals and sea birds, which may also be predators of salmonids (Rogers 1984).

A feature common to many studies of biological production is the identification of periods of high or low abundance of the study organism. That is, shifts in the abundance of many organisms appears to have coincided with shifts in salmon abundance in the late 1970s (Rogers 1984). Two interventions (statistically significant changes in the mean of a time series) have been found in Alaskan pink and sockeye salmon abundance between 1919 and 1988: (1) one occurring in the late 1970s (increase), and (2) the other occurring in the early 1950s (decrease) (Hare and Francis 1993). The intervention (increase) in the late 1970s was more pronounced than the earlier intervention (decrease) and matches well with the shift noted by Rogers (1984) and Ward (1993). Also, the timing of the 1970s intervention has most often been correlated to the timing of changes in the abundance of other organisms. Similar relationships have been found to exist between oceanic conditions and sea birds (Decker and Hunt 1993). The abundance of zooplankton, several species of fish, and cephalopods in the central Subarctic Gyre changed significantly from the period of 1956-1962 to 1980-1989 (Brodeur and Ware 1992). These changes also corresponded to a 1.7 fold increase in the estimated biomass of salmonids between the periods of 1956-1962 and 1980-1984 (Rogers 1987). In addition, an eighty percent decrease was found in macrozooplankton off southern California (in the Southern California Bight and near Point Conception) from 1951 to 1993, with potentially the majority of this decline occurring rapidly since the 1970s although a gradual decline over the whole time series is also possible (Roemmich and McGowan 1995).

Francis and Sibley (1991) and Francis et al. (1992) have developed a model linking decadal-scale atmospheric variability and salmon production that incorporates hypotheses developed by Hollowed and Wooster (1991) and Wickett (1967), as well as evidence presented in many other studies. The model developed by Francis et al. (1992) described a time series of biological and physical variables from the Northeast Pacific which appear to share decadal-scale patterns, most notably synchronous shifts in mean conditions during the late 1970s and out-of-phase relationship between variables in the Coastal Upwelling and Coastal Downwelling domains. Biological and physical variables which appear to have undergone shifts during the late 1970s include the following: salmon (Rogers 1984, 1987, Hare and Francis 1993); other pelagic fish, cephalopods, and zooplankton (Brodeur and Ware 1992); oceanographic properties such as current transport (Royer 1989); surface sea temperature and upwelling (Holowed and Wooster 1991); and atmospheric phenomena such as atmospheric circulation patterns, sea-surface pressure patterns, and sea-surface wind-stress (Trenberth 1990). Biological variables from the Coastal domains which appear to fluctuate out-of-phase include: salmon (Francis and Sibley 1991); current transport (Wickett 1967, Chelton 1983); sea surface temperature and upwelling (Tabata 1984, Hollowed and Wooster 1991); and zooplankton (Wickett 1967).

Two states (Type A and B) of winter atmospheric circulation in the North Pacific may exist which lead to two sets of oceanographic conditions (Francis et al. 1992). Type A is characterized by: 1) the absence of a strong Aleutian Low with its center located in the western North Pacific, 2) enhanced westerly winds in the eastern Pacific, 3) a more northerly bifurcation of the Subarctic Current, 4) enhanced southward flow at the bifurcation resulting in increased advection into the California Current, 5) decreased advection into the Alaskan Current, and 6) negative sea surface temperature anomalies throughout the Northeast Pacific. Type B is characterized by: 1) a strong Aleutian Low located over the eastern North Pacific, 2) enhanced southwesterly winds in the eastern Pacific, 3) a more southerly bifurcation of the Subarctic Current, 4) enhanced northward flow at the bifurcation resulting in increased advection into the Alaskan Current, and 5) positive sea surface anomalies throughout the Northeast Pacific. Zooplankton abundance in the Coastal Domains may also be primarily influenced by fluctuations in flow of the Alaska and California currents, which are determined upstream near the bifurcation of the Subarctic Current (Francis et al. 1992).

The strength of the California Current appears to be somewhat regulated by the relative strengths of the Aleutian Low and North Pacific High pressure systems (Chelton and Davis 1982). In years when the Aleutian Low pressure system is very strong, counter-clockwise flow of water around the Gulf of Alaska intensifies, the latitude where the West Wind Drift splits into the Alaska and California Currents moves to the North (around British Columbia) and the California Current weakens (Chelton and Davis 1982). Conversely, in years when the Aleutian Low pressure system is weak and the North Pacific High pressure system is strong, there is an increased flow into the California Current and the division of the West Wind Drift into the Alaska and California Currents moves to the South (around the state of Washington). Flow of cool-nutrient rich subarctic water into the area off Oregon and California is enhanced in years when the California Current is strong. Coastal sea level and surface temperatures are low in years of strong California Current flow relative to years when flow is weak (Chelton et al. 1982).

During the period from the mid-1940's to the mid-1970's winter low pressure over the northern Pacific Ocean was generally weak and sea surface temperature in the California Current was generally low indicating that this was a period of strong southward flow in the California Current (Ward 1993). However, periods from early 1920's to the early 1940's and from the mid-1970's to present were characterized by a stronger winter low pressure system in the North Pacific and higher coastal sea surface temperatures indicating a weaker southward flow in the California Current (Ward 1993).

Finally, near-shore conditions during the spring and summer months along the California coast may dramatically affect year-class strength of salmonids (Scarnecchia 1981). Coho salmon along the Oregon and California coast may be especially sensitive to upwelling patterns because these regions lack extensive bays, straits, and estuaries that are found along the Washington, British Columbia, and Alaskan coast that could buffer adverse oceanographic effects (Bottom et al. 1986).

The paucity of high quality near-shore habitats and variable ocean conditions makes freshwater habitat more crucial for the survival and persistence of anadromous salmonids. Undoubtedly, smolts that are slow-growing and of poor condition will face the greatest risk upon entering the ocean. This fact is of particular importance for recovering the weak winter-run chinook population. The message for winter-run chinook recovery then is that ocean survival rests upon having high quality juveniles entering the ocean.

El Niño

An environmental condition often cited as a cause for the decline of west coast salmonids is the condition known as "El Niño". California's climate is strongly influenced by ocean-atmosphere dynamics, and El Niño is but one dominant mode of variability in the system.

El Niño is an unusual warming of the Pacific Ocean off South America and is caused by atmospheric changes in the tropical Pacific Ocean (southern Oscillation-ENSO). El Niño events occur when there is a decrease in the surface atmospheric pressure gradient from the normal steady trade winds that blow across the ocean from east to west on both sides of the equator. There is a drop in pressure in the east off South America and a rise in the pressure in the western Pacific. The resulting decrease in the pressure gradient across the Pacific Ocean causes the easterly trade winds to relax, and even reverse in some years. When the trade winds weaken, sea level in the western Pacific Ocean drops, and a plume of warm sea water flows from west to east towards South America, eventually reaching the coast where it is reflected south and north along the continents.

The effects of El Niño conditions on the coastal ocean are mediated by several mechanisms. The dominant one is passage of Kelvin waves (long-wavelength, coastally trapped waves) that strike the American west coast, and then travel poleward. These waves carry warm water and depress the thermocline. The depression of the thermocline means that local upwelling brings up warm, nutrient poor water to the surface, which does not fuel primary production. Also, re-organization of the high and low pressure systems results in a weakening of the coastal jet along California, which decreases transport of cool, nutrient-rich, high production subarctic waters in the California Current. The weaker jet also reduces local upwelling. In addition, rainfall can be much higher or much lower than normal in California during El Niño conditions. The amount of rainfall depends on: 1) the strength of the Aleutian storms; 2) how far south the storms travel before making landfall; and 3) the position and strength of high and low pressure systems.

Several recent El Niño events have been recorded during the last several decades, including those of 1940-41, 1957-58, 1982-83, 1986-87, 1991-1992, and 1993-94. Effects of temperature on productivity would be most noticeable during strong El Nino events such as the 1983 event, the strongest in recent history. Total catch and average weight of chinook salmon landed in commercial and sport fisheries along the coast were lower during that event (Pacific Fishery Management Council 1984, Pearcy et al. 1985, Johnson 1988).

There are several reasons to suspect that El Niño-southern Oscillation events affect the growth and survival of winter-run chinook salmon, although there is not a clear and certain demonstration of an effect. The reasons are based on: (1) general knowledge of the effects of El Niñoevents on the coastal ocean as discussed above, and (2) observed effects on fall-run chinook Sacramento River chinook salmon.

Abundance of Sacramento River fall-run chinook covaries strongly with El Niño conditions during the summer before the spawning run, and weakly with El Niño conditions during the months in which they enter the ocean as smolts (Kope and Botsford 1990). The dominant principal component of temperature, sea level height, and upwelling index in the coastal ocean off California represents the effects of El Niño events (i.e., higher temperature, higher sea level, and lower upwelling index). Spawning abundance and catch are negatively correlated with El Niño conditions during the summer in which they are caught or are preparing to spawn. There is also a weaker positive correlation with El Niño conditions in the month in which juveniles enter the ocean. The unexpected sign of this relationship may be due to northward shifts in the distribution of prey species such as clupeid larvae (see Kope and Botsford 1990 for further details), or potentially due to high rainfall leading to increased juvenile survival. That is, different relationships may occur between juveniles and adults because they occur in different habitats which are undergoing varying physical changes due to El Niño conditions (i.e. juveniles may experience beneficial, high flows in the river, while adults experience lower food availability). Similar relationships between winter-run chinook abundance and El Niño conditions are difficult to demonstrate due to limited data. However, it is reasonable to assume that winter-run chinook are affected similarly by ocean conditions.

In general, salmon will be strongly affected by El Niño conditions in ways that are inherently unpredictable. Similar to the discussion above on ocean conditions, anadromous salmonids have managed to persist in the face of numerous climatic events and changes. The long-term persistence of winter-run chinook salmon is dependent upon the population being sufficiently robust enough to withstand environmental conditions. It is apparent that the tremendous loss of freshwater habitat, in combination with extremely small population levels, are allowing salmonid populations to become increasingly vulnerable to extirpation through natural events. Up until recently when salmonid population levels reached critical levels, these environmental conditions have gone strongly unnoticed (Lawson 1993). Therefore, it would seem that environmental events and their impacts on winter-run chinook salmon and other depressed salmonid populations, serve more as an indication of unstable population levels rather than a direct cause of such a decline.

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